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Proceedings of a Symposium Held at
Cincinnati, Ohio on September 19-21,1979

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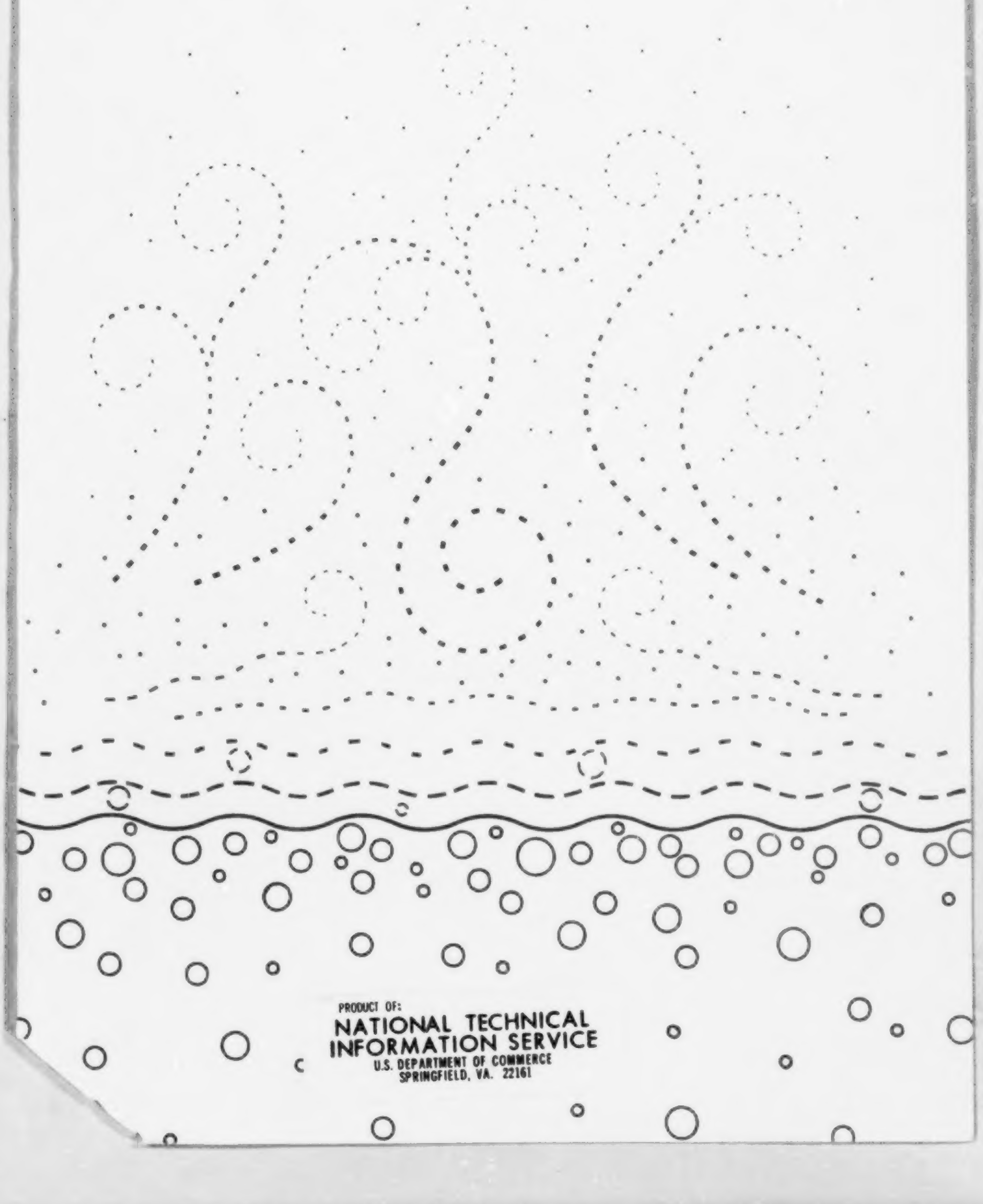

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Wastewater Aerosols and Disease

Proceedings of a Symposium

September 19–21, 1979

Sponsored by the
Health Effects Research Laboratory

Edited by
H. Pahren and W. Jakubowski

OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our national environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The primary mission of the Health Effects Research Laboratory in Cincinnati (HERL) is to provide a sound health effects data base in support of the regulatory activities of the EPA. To this end, HERL conducts a research program to identify, characterize, and quantify harmful effects of pollutants that may result from exposure to chemical, physical, or biological agents found in the environment. In addition to the valuable health information generated by these activities, new research techniques and methods are being developed that contribute to a better understanding of human biochemical and physiological functions and how these functions are altered by low-level insults.

These proceedings represent an attempt to publish current knowledge on the human health aspects of exposure to microbial aerosols from wastewater treatment plants. With a better understanding of these health effects, design engineers, municipal officials, and persons involved with regulatory decisions can make more informed judgments on the siting and operation of such plants.

R. J. GARNER
Director
Health Effects Research Laboratory

PREFACE

Many wastewater treatment plants are constructed in urban areas close to residential areas. These systems generally contain aeration basins or trickling filters where there is an opportunity for small droplets of wastewater to be emitted. These droplets, which could contain a bacterium or virus, evaporate very rapidly to yield small droplet nuclei known as aerosols.

A number of persons have investigated the types of organisms emitted and their concentration in the air as a function of distance from the treatment plant. These microorganisms travel passively with the wind, and their concentration decreases with time and distance as a result of atmospheric dispersion, die-off, and deposition. The potential for plant workers and nearby residents to inhale viable organisms certainly exists. However, there has never been a systematic investigation to confirm or negate the existence of a health hazard from these viable wastewater aerosols.

With this background, the Health Effects Research Laboratory of the U.S. Environmental Protection Agency arranged for several epidemiological studies to gather information on health effects associated with aerosols from uncovered wastewater treatment plants. These studies were conducted by personnel from universities or research institutions.

The purpose of this symposium was to present and discuss the results of the epidemiological studies, as well as related health topics which could aid in understanding the findings. The symposium brought together interested persons from several countries, who contributed freely and provided an opportunity to summarize the current knowledge in a single publication.

The proceedings are organized according to the format of the symposium into six main sections addressing the topics of contaminants, health fundamentals, population studies, occupational studies, and aerosol suppression and providing an assessment. In many cases, the proceedings papers are more comprehensive than the symposium presentations to provide a more thorough coverage of a given topic. Edited discussions are included with the papers, and an attempt was made to identify each questioner. A list of registrants is presented to allow the reader to contact any participant for further information.

Herbert R. Pahren
Walter Jakubowski
Editors

ABSTRACT

The Health Effects Research Laboratory of the U.S. Environmental Protection Agency sponsored a Symposium on Wastewater Aerosols and Disease on September 19-21, 1979, in Cincinnati, Ohio.

This symposium brought together scientists, engineers, physicians, and public health officials from all over the world to present and discuss current state-of-knowledge on human health aspects of exposure to microbiological agents emitted as aerosols from wastewater treatment plants. Sessions on the nature of the contaminants, health aspects, epidemiological studies, and aerosol suppression and a panel discussion assessing the information were held. The proceedings consist of 22 invited papers and associated discussions.

ACKNOWLEDGEMENTS

The assistance of the many individuals who contributed to the success of this symposium and the timely completion of the proceedings is gratefully acknowledged. Special appreciation is due to the speakers, for the quality of their presentations and promptness in submitting their papers, the session chairmen, and the many participants who contributed to the discussions.

We also wish to acknowledge the assistance of JACA Corp. and the EPA Center for Environmental Research Information in providing the many administrative services in connection with arranging the symposium and issuing the proceedings. We are also indebted to Lon Winchester for handling the distribution of publications and typing in connection with the proceedings.

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Wastewater Aerosols: Is The Challenge Only Scientific?

ABSTRACT

This paper discusses the challenges of wastewater aerosols. Are those challenges only scientific? The author believes the answer to that question is no.

Scientists are responsible for conducting research, obtaining data, interpreting data, and drawing conclusions based on that data. However, the scientist's role does not end when results of his or her work are published. On the contrary, the published report becomes an extension of the scientist when it influences decisionmakers.

Since conclusions in research reports may be used to set policy, the scientist should be aware of challenges other than the scientific challenge when he conducts research. Those other challenges are: 1) risks; 2) costs to put the research into effect; and 3) the need to make explicit recommendations based on research results.

Other challenges of aerosols are particularly important to the Environmental Protection Agency's Construction Grants program. Decisions made based on results of aerosol studies could significantly increase costs of projects funded through that program. This emphasizes the need for the scientific community to be aware of the implication of their studies and to recognize all challenges of the aerosol issue.

I am delighted to speak to this particular group since I have seen your work influence agency policy. I know you will find the information presented here interesting and useful.

We are going to review research on wastewater aerosols and disease.

Now, why is it important to stand back and take a look at the research done on aerosols? I believe, basically, there are three major reasons.

First, it is important to be aware of the work of other researchers. Knowledge of other research approaches, other analytical techniques, and other research results—all help us better understand the problems and the issues.

Second, it is important to take a look at this research so future research can be planned. Knowledge of what research has already been done can help prevent duplication. Then, too, it can help us plan future research.

And, third—personal contact—meeting the people who conduct the research. So often, important information does not find its way into a report. This information can be shared through contact with the people who did the research.

Let me start the program by asking a question. Does the scientist face only a scientific challenge in research on aerosols? I believe the answer to that question is no.

I have heard some scientists say they are not politicians, administrators, or regulators; they are only concerned with the scientific aspects of an issue. I do not agree with that statement. Scientists are responsible for conducting research, obtaining data, interpreting data, and drawing conclusions based on that data. However, the scientist's role does not end when the results of his or her work are published. On the contrary, the published report becomes an extension of the scientist when it influences decisionmakers.

Often, decisionmakers use the scientist's conclusions as a basis for setting policy. So the scientist must realize the practical implications of his work, especially when results are published. This is not to say that research purely for its own sake is bad. But the scientist should recognize that he does not operate in a vacuum—policymakers may use his results to set policy that affects everyone, including the scientist himself. In those situations, the scientist's role is clearly more than just scientific.

What are some of the other challenges that scientists face? Let me illustrate them by talking about research results on wastewater aerosols.

Some research indicates that aerosols may pose a health hazard to people exposed to them. Other results indicate aerosols do not pose a health hazard, and still other results are inconclusive. For scientists to say *at this time* that we should take all precautions to protect people from the health hazards of aerosols does not recognize other parts of the aerosol issue. It does not take into account the acceptable risks from exposure to aerosols; it does not take into account how much it will cost to provide protection; and it does not take into account the construction delays on wastewater treatment plants caused by a lack of agreement on whether aerosols are a health hazard. The statement recognizes only that some people exposed to aerosols become sick even though the cause of the illness may be something besides aerosols. So the other challenges to scientists are: 1) to consider the risks; 2) to recognize the costs to put the research results into effect; and 3) the need to make explicit recommendations based on research results.

Risks are a very important challenge of the wastewater aerosol issue. If all precautions were taken to protect people from the health hazards of aerosols, then we would assume that no exposure to aerosols is acceptable. That would be the ultimate protection and no risks would be allowed. Do we really need this ultimate protection from wastewater aerosols?

W. W. Lowrance,* in his book "*Of Acceptable Risk: Science and the Determination of Safety*" defines risk as "a measurement of the probability and severity of harm to human health." He further states, "This definition emphasizes the relativity and judgmental nature of the

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*Lowrance, W. W. 1976. *Of Acceptable Risk: Science and the Determination of Safety.* William Kaufman, Inc., Los Altos, California.

concept of safety. It also implies that two very different activities are required for determining how safe things are: *measuring risk*, an objective but probabilistic pursuit; and *judging the acceptability of that risk (judging safety)*, a matter of personal and social values judgment."

The scientist is responsible for measuring the risks. To do that, the scientist should collect enough data so that he or she can determine exposure-effect and exposure-response relationships. Without that exposure-effect data those relationships are difficult to assess. And without those relationships, judging the acceptability of the risk is even more difficult.

After the scientist measures the risk and determines the exposure-effect and exposure-response relationships, the policymaker judges whether this risk is acceptable and sets standards to protect the public. The scientist's role in setting standards assures that the information on which these standards are based is sound and not the result of speculation and different opinions. That is very important. It emphasizes the need for the scientist to be aware of what will be done with the results of his work. An assessment of risks is an important aspect of any research. It is especially important in research on wastewater aerosols and other health-related issues.

Costs to implement the research results are also an important challenge. As most of you know, I am the National Program Manager of EPA's Construction Grants program. We give communities grants to help them build new wastewater facilities and to upgrade old wastewater facilities. So I am acutely aware of the impact of costs on the construction of wastewater facilities. Let me illustrate with an example that relates to the aerosol issue.

The North Shore Sanitary District received a grant from EPA to upgrade the Clavey Road Wastewater Treatment Plant in Highland Park, Illinois, and to expand the capacity of that plant from about 4½ mgd to about 18 mgd. During that time it took to plan, design, and construct the Clavey Road plant, areas adjacent to the plant developed. Residents who lived near the plant became concerned about the potential odor problem and the potential health hazards of aerosols from the treatment plant. They sued to make the North Shore Sanitary District do something about those potential problems.

As a result of litigation, the Sanitary District installed odor control equipment and covered all the treatment plant units, including six large retention basins. It cost over $8½ million to cover those units. That was about 24% of the total capital costs for upgrading and expanding the entire treatment plant.

This illustrates the enormous cost to protect people from the potential hazards of aerosols. Those costs are even more staggering when you consider that not all researchers and health authorities agree there are any health hazards from exposure to wastewater aerosols.

EPA's *1978 Needs Survey* says there will be about 23,000 wastewater treatment plants in the United States by the year 2000. Of these plants, 285 will have a flow rate between 10 mgd and 50 mgd. The cost impact on EPA's Construction Grants program just to cover that slightly more than 1% of the total number of treatment plants for aerosol protection would be severe. That impact would also be felt by the communities that have to pay both the local share of an EPA-funded project and the operation and maintenance costs of that project. So—to repeat—the scientist must be aware that his research results do have a cost impact when they are used to set policy.

The last challenge I want to talk about concerns the recommendations a scientist makes based on the results of his research.

When I was the Water Division Director at EPA's Region V office in Chicago, we initiated the O'Hare Aerosol Suppression Study. That study was in response to a proposal that aerosol suppression equipment be installed at the O'Hare wastewater treatment plant because of the health hazard posed by the aerosols. Before we approved that proposal, we required that the aerosol issue be studied.

Phase 1 of that study is nearly complete. We are collecting background samples of the ambient air around the O'Hare plant and analyzing them for bacteria. When the plant begins operation, we will collect more samples and analyze them for bacteria. Results of the two sampling programs will be compared to see whether the aerosol suppression equipment is justified. They will also be compared with findings of other research.

The approach taken at the O'Hare plant is a good one. It insists that the hazard be verified before we spend a lot of money for control equipment. But it also requires that the scientists who conduct the sampling study make scientific recommendations based on the results of the study. The challenge for the scientist is to make explicit recommendations and to support those recommendations at all times.

That challenge applies to all researchers and not just those involved in the O'Hare study. For example, EPA is involved in an issue of what concentration of cadmium should we allow in sludges applied to the land. Some research reports indicate that the concentration should be a certain value. Researchers who prepared those reports indicate, when you talk to them, that a different value may be acceptable. This "conflict" is a major problem. Some researchers in this situation did not make explicit recommendations that they could continue to support without expansion or clarification when questioned. This leads to conflicting statements regarding published reports and possibly conclusions not supported by actual data.

As you listen to the speakers at this symposium, I hope you will remember the question I asked at the beginning of my talk: Is the challenge of wastewater aerosols only scientific? I hope you will ask the question when you go back to your offices and plan future research on aerosols. I also hope you will keep in mind the challenges I have discussed. Beside the scientific challenges, remember the other challenges —risk factors, cost impacts, and explicit recommendations. Decisions will be made—you should participate!

DISCUSSION

SPEAKER: I like to think of myself as a very pragmatic scientist. I am also a professional school teacher. I have taught my students that we scientists are to cooperate with each other, to be interdependent, and to share our knowledge. Then when I met the world of reality; I found out that wasn't the case. I am ashamed of our groups of scientists. Each one seems to have his own little empire, and we don't seem to be able to get together anymore. Perhaps it is just the trend of the nation.

MR. LONGEST: What I tried to do here was to stimulate you and challenge you. I recognize the pressure the scientist is under when putting his or her name to a document that goes out and may be used in a court case.

The point that I am trying to get across is that I feel very strongly that the scientist cannot just walk away and say, "Well there are my scientific conclusions." I do recognize the position that the scientists are in.

But decisions are being made daily, whether the data are good or not. The better you can help us in terms of explicit recommendations based on the best information you have, recognizing that you may not find that information completely to your satisfaction, the better our output will be. You might be amazed at how many decisions are made on information that is much less complete than what you are providing. You are part of the decisionmaking process; I encourage you to remain a part of the process and recognize that these decisions are going to be made.

DR. SPENDLOVE: As scientists, we are required to characterize the aerosols. I think the crux of the whole situation is the risk question. I would like to ask if you would give us a little more information on risk, and what you are willing to define in terms of risk. I would like to hear a little bit more of what your definition of risk means.

MR. LONGEST: I am certainly not going to answer that loaded question, but I will talk around it for a minute. I think the key thing is that many times the aerosol issue is used instead of another reason. I won't name the specifics, but I know of several facilities where there is no doubt in my mind that the aerosol risk is not the issue. The issue is, "I don't want a sewage treatment plant in my backyard."

So what I am trying to say is let's first determine if there is a risk for the treatment plant neighbors. If so, let's say what that risk is, relative to the risk of the operators working in the sewage treatment plant. That must be considered. Then we should determine if that risk is the same as or different than that for the person who lives 1,000 yards from the sewage treatment plant.

Without giving some types of explicit recommendations, I am not talking in terms of life lost but specifically about the proven chances of someone getting ill from living near a sewage treatment plant, comparing that chance with the cost, and then finding out if there really is a health issue in that particular situation, or whether it is just an excuse to stop treatment plant construction in somebody's backyard.

Methods For Detecting Viable Microbial Aerosols

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ABSTRACT

Aerosols formed during processes of wastewater treatment can contain viable microorganisms that survive transport to distant locations from the site of origin. Detection of such viable microbial aerosols under field conditions requires the application of reliable methodologies capable of attaining acceptable sensitivity levels. These acceptable levels should be determined before initiation of sampling activities. Determination of low-level concentrations of viable microbial aerosols in the ambient environment requires sampling at relatively high air flow rates for long time periods.

Aerosol collection concepts such as sedimentation, filtration, impingement, precipitation, centrifugal separation, or inertial impaction may be employed, provided the sampling devices can be sterilized and can maintain the viability of collected organisms without permitting growth. Widely used samplers such as all-glass impingers and multistaged impactors are suitable for detecting high microbial aerosol concentrations but, due to their relatively low sampling rates, may not be applicable when very low microbial aerosol levels are anticipated. For applications requiring greater air sampling sensitivity, devices with higher air sampling rates have been developed. These "large volume air samplers" include inertial impactors, electrostatic precipitators, and centrifugal separators, each with unique advantages and disadvantages. Among the criteria that should be considered in viable microbial aerosol sampler selection are: collection efficiency, sampling sensitivity, reliability, ease of sterilization, maintenance of collected sample viability, ease of sample assay, remote operation capability, particle size discrimination, and cost.

Studies with appropriate sampling devices require implementation of a vigorous quality assurance program in both the field and analytical laboratory. Meaningful data interpretation may require consideration of basic meteorological parameters as well as the limitations of the methodologies employed.

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Domestic sewage can be a source of potentially pathogenic bacteria, viruses, parasites, and fungi that may initiate infections in susceptible hosts upon exposure (1,2). Such exposure may occur through direct sewage contact; contact with contaminated fomites; ingestion of contaminated water or food; or inhalation, ingestion, or contact with microorganism-containing sewage aerosols. The occurrence of microorganisms in sewage aerosols has been demonstrated, and the reports of many of these investigations have been reviewed (3). Existing studies have focused upon evaluation of the aerosols emitted by such wastewater treatment processes as activated sludge, trickling filtration, and land application by spray irrigation. Inherent characteristics of each treatment process determine the method of aerosol generation.

The process of activated sludge treatment, for example, generates small bubbles by diffused air aeration that rise through the sewage depth in the aeration tank to the surface boundary. The formation of sewage aerosols during aerobic wastewater treatment and their emission as mists or droplets have been demonstrated (4). Rising bubbles can adsorb and concentrate suspended bacteria and viruses while moving toward a liquid surface (5,6). At the surface boundary, a film containing microorganisms is disrupted by the rising bubbles which burst, releasing tiny aerosol droplets containing the bubble-adsorbed, as well as the surface film-associated, microorganisms. The characteristics of aerosols generated by processes of spray irrigation are affected by machinery design as well as by prevailing meteorological conditions (7). Spray irrigation equipment produces large quantities of respirable aerosols whose number increases as a function of windspeed and length of time exposed to the wind. (8). During treatment by trickling filtration, impacting sewage onto rocks within the trickling filter unit causes a splashing effect, resulting in sewage aerosol formation (9). The nearly instantaneous evaporation which may occur as these droplets become suspended in air leaves a dried residue referred to as a droplet nucleus (10), subject to downwind dispersion dependent on its size, density, and on prevailing meteorological conditions. The net effect of sewage-borne aerosol formation is that procedures of water pollution abatement become potential contributors to air pollution problems that should be assessed in terms of exposure risks and effects on human health.

The purpose of this presentation is to review and present some concepts behind the design and implementation of field studies for ambient viable microbial aerosol detection from facilities such as wastewater treatment operations.

FIELD STUDY INITIATION

Approach

Field studies of microbial aerosols, initiated as specific research investigations or as monitoring programs intending to answer questions with health, political, economic, or regulatory implications, are dependent upon the clarity of proposed objectives for their ultimate success. These objectives are the basis of study site selection, experimental design, methods selection, and monitoring strategies. The study site selection is also dependent upon factors such as physical accessibility, cooperation of local governmental officials, and density and location of a potentially exposed population. Since the study objectives may require aerosol concentration discrimination on the basis of time, location, season, particle size, or atmospheric stability, an experimental design may require utilization of several sampling instruments at numerous locations at specified time intervals. Determination of both sampling frequency and number of sampling locations should be made in an effort to obtain statistically reliable data. A compromise between either sampling frequency or number of sampling locations may, however, be required when resource limitations are a factor.

Sampling Sensitivity

Guidelines regarding required microbial aerosol detection sensitivities have not been defined. As a result, air sampling volumes collected during specific field studies are often based upon the constraints of existing sampling methodologies and may be below the sensitivities required for detection of low-level aerosols. The significance of nonpositive observations is dependent upon the proportion of the total air volume being sampled, which is very small in open air, and upon the efficiency of the collection and assay systems. With this in mind, negative observations must be interpreted in view of the detection sensitivities attained. Prior to initiating a field sampling program, the investigator should determine a level of acceptable sampling sensitivity at which negative observations will be interpreted as inconsequential.

A level of acceptable risk of exposure, and resultant sampling sensitivity, to microbial aerosols has not yet been determined but may be based upon either individual or population exposure. That is, either the exposure of an individual over a limited time period (11) or that of a susceptible population of a certain size and density may be emphasized in such risk determinations. With the latter approach, introduction of an infection into a population via droplet nuclei and subsequent transmission by effective contact between susceptible and infected individuals should be considered (12).

VIABLE MICROBIAL AIR SAMPLING INSTRUMENTATION

Description of Representative Samplers

Background

While health effects can be assessed by epidemiological methods, determination of risks of exposure requires the application of reliable methodologies capable of detecting airborne microbial contaminants at acceptable sensitivity levels. Sample collection from open air is complicated by a high dilution factor for dispersed particulates. Consequently, attaining the sensitivity required for detecting source-related infectious microbial aerosols at the threshold of acceptable risk may require sampling at relatively high air flow rates for long time periods. Extensive instrumentation, based on widely varying concepts, has been developed for detecting viable microbial aerosols. Each device has unique characteristics which often result in differences in collection efficiencies for aerosols in certain size ranges, sampling capacities, and operational capabilities that make comparisons of data collected with different samplers or under differing conditions very difficult. Although an attempt was made to recognize certain low-volume samplers as standards for studies in aerobiology (13), the need for samplers of greater sensitivity for field studies has resulted in the development of nonstandard large volume air samplers based upon different collection concepts. The principle aerosol collection concepts which have been used in aerobiology are sedimentation, filtration, impingement, impaction, and cyclone scrubbing. Typical examples of the application of each concept for viable microbial aerosol collection are presented in Table 1.

Type of sampler	Collection Medium	Air sampling capacity	Comment
Sedimentation:			
Open petri dish	Agar surface	Low	Simple, inexpensive, non-quantitative, favor particles with high settling velocity
Filtration:			
Membrane filter	Membrane	Low	Simple, relatively inexpensive, viability losses due to desiccation of fragile organisms
Electrostatic Precipitation:			
Litton Model M LEAP	Compatible fluid	High	Complex, expensive, electrical arcing sterilization difficult, efficient
Centrifugal separation:			
Cyclone scrubber	Compatible fluid	High	Simple, relatively inexpensive, operation subject to relative humidity variations, autoclavable
Impingement:			
All-glass impinger	Compatible fluid	Low	Simple, inexpensive, dependable
Multistage impinger	Compatible fluid	Low	Simple, relatively inexpensive, size classification
Multislit impinger	Compatible fluid	High	Complex, expensive, undependable, sterilization difficult, efficient for large particles
Impaction:			
Slit sampler	Agar surface	Low	Simple, particle time discrimination
Multistage impactor	Agar surface	Low	Simple, relatively expensive, particle size discrimination, dependable

Table 1. Selected Viable Microbial Aerosol Sampling Concepts and Instruments

Sedimentation

Settling plates (Figure 1) offer a simple and inexpensive method of microbial aerosol collection. The aerosol particles are permitted to settle on a nutritional agar-based medium contained within petri dishes. Following incubation, colonies are counted and the general level of contamination for a defined time period is assessed. This procedure, used for both intramural and extramural aerosol sampling (14,15), has been suggested as a standard method for detection of bacteria in ambient air (16). Although this method determines the number of viable particles which adhere to the exposed plate, their impaction onto the agar surface depends upon the air flow velocity and angle as well as the particle size and density (17). Large particles of greater density have a higher settling velocity than smaller particles of lower density (18) and are, consequently, collected more efficiently. Since smaller particles are more likely to achieve deep lung penetration than are larger ones (19), the value of microbial aerosol collection by sedimentation in the assessment of the risk of respiratory infection is limited by its failure to detect more minute aerosols.

Filtration

Filtration (Figure 2) offers another simple and relatively inexpensive commercially available means of efficient removal of microorganisms

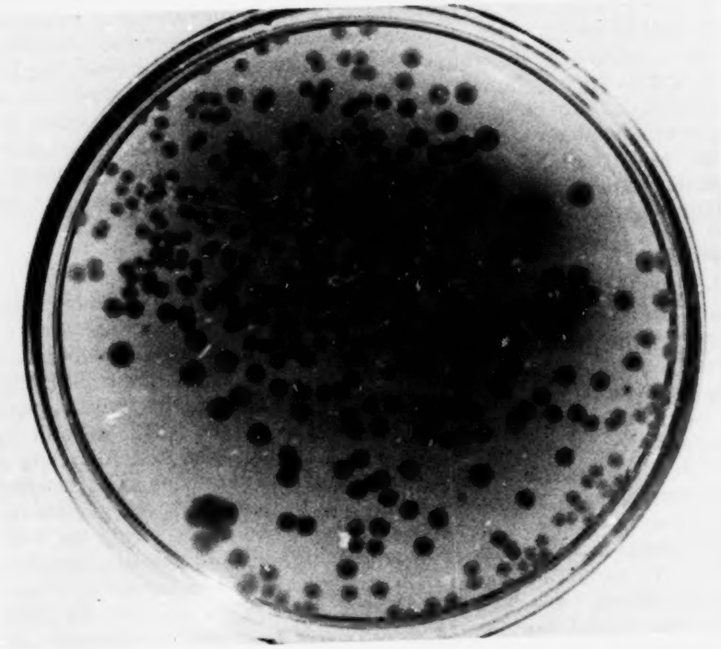


Figure 1. Nutrient Agar-Filled Settling Plate with Collected Microorganisms

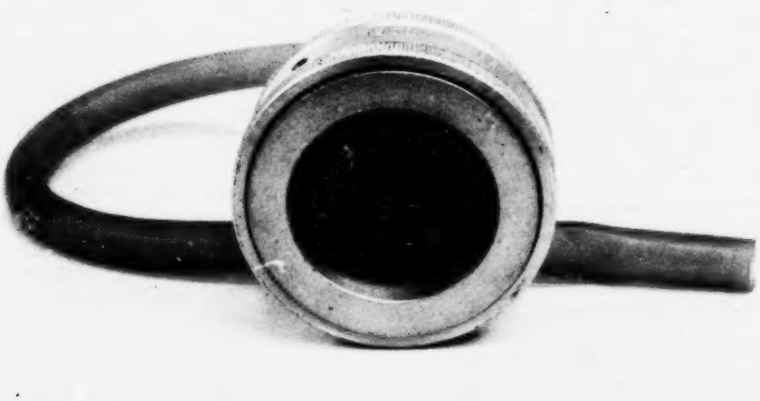


Figure 2. Membrane Filter Aerosol Sampler

from an airstream. The applicability of filtration devices such as cotton (20), soluble gelatin (21), or membrane filters (22) as viable microbial aerosol samplers is determined by characteristics of the study organisms. Stable microorganisms such as *Bacillus subtilus* var. *niger* spores, for example, can be efficiently recovered by filtration (23) while the recovery of viable vegetative *Serratia marcescens* has been shown to be as low as 0.1% to 2% under certain conditions (24). Viability losses due to desiccation of fragile organisms makes use of filter samplers impractical for long-term or large-volume sampling applications.

Impingement

As used in this presentation, impingement refers to striking into rather than onto a collection medium. Liquid impinger samplers are used to determine the number of viable microorganisms in aerosols, rather than the number of viable aerosol particles (25). The all-glass impinger (AGI) (Figure 3) is a simple, inexpensive, easily sterilized device (26) designed for isokinetic sampling of dynamic aerosols (27) at 0.0125 m^3/min by high speed impingement into a collecting medium. The AGI-30 (having a jet-to-base distance of 30 mm) was recommended as a standard sampler by a committee of aerobiologists (13). To minimize microorganism reatomization (28) and vegetative cell destruction (29) during the high speed impingement process, low speed bubbling and washing samplers such as the midget impinger, fritted bubbler (27), and tangential impingers (25,30) were developed. A preimpinger (31), for use with the AGI, and a multistaged liquid impinger (26) have been used for aerosol size discrimination.

Impinger sampling fluid is under low pressure and tends to evaporate quickly and freeze in cool dry air (32). Changes in fluid pH, volume, and osmotic pressure can occur during liquid impingement necessitating sampling time restrictions (33). Relatively low air sampling rates and short permissible sampling durations limit the sensitivity of impinger samplers. To increase impinger sampling capacity and, hence, sensitivity, multiple devices were run in parallel (34), multiple jet impingers used (35), a continuous impinger constructed (36), and a large volume multi-slit impinger (MSI) developed (37).

The MSI, which collects aerosol particles at an air sampling rate of about 1 m^3/min by inertial impaction into a liquid film-coated rotating disc, has been used in field studies of wastewater-generated microbial aerosols (38). Although the MSI collection efficiency, compared to an AGI-30, was reported to be 82% for *S. marcescens* and 78% for *B. subtilus* var. *niger* spores (37), ". . .reliability, maintainability and portability were considered to be of less importance. . ." in the MSI design than demonstrating the theory of operation (39). In addition to difficulties in field dependability (38), the MSI does not lend itself to conventional sterilization procedures prior to sample collection.

Electrostatic precipitation

Microbial aerosols carrying a charge can be collected with relatively high efficiency by drawing them over an oppositely charged agar surface (40,41,42,43). The concept of aerosol collection by electrostatic precipitation onto a wetted surface has been employed in the development of large volume air samplers with air sampling rate capacities ranging from about 1 to 10 m³/min. Both the Litton Model M (LVAS) (44) (Figure 4) and the Environmental Research Corporation LEAP (45) electrostatic

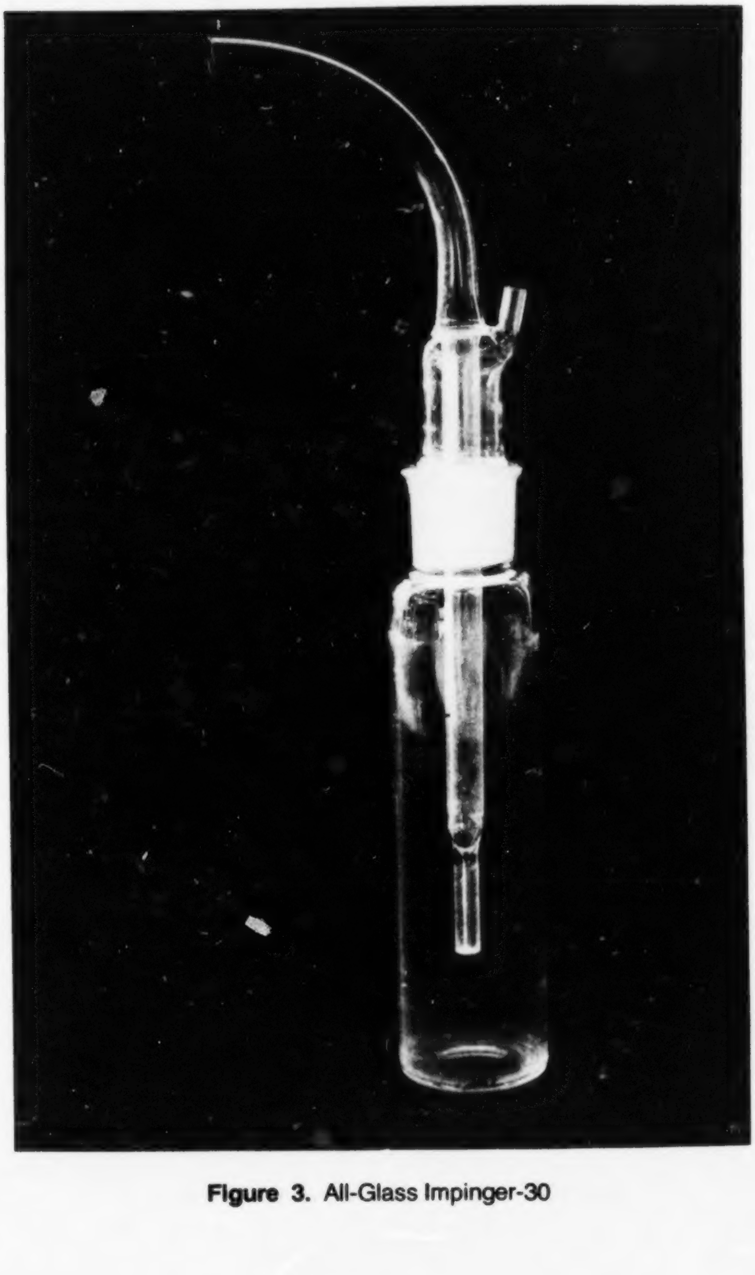


Figure 3. All-Glass Impinger-30

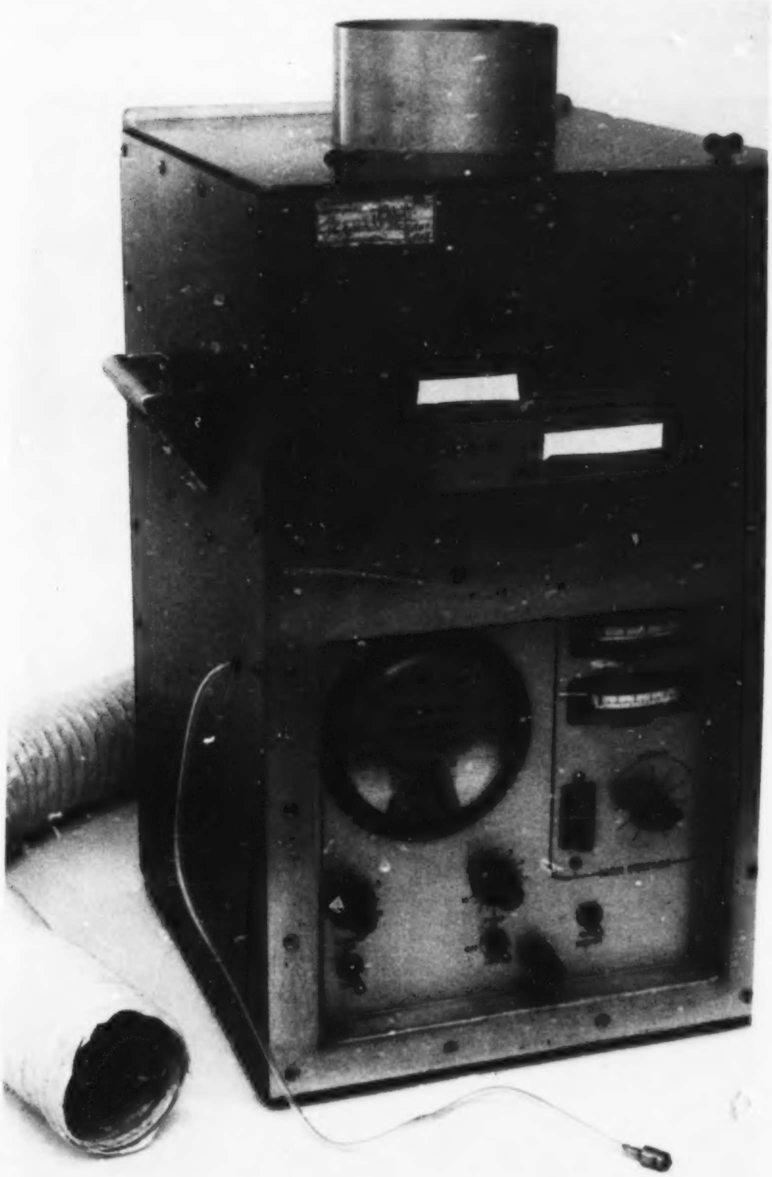


Figure 4. Litton Large Volume Air Sampler

precipitator large volume air samplers have been used in field studies of wastewater-generated microbial aerosols (38,46).

A comparative evaluation of the MSI and the LVAS showed that their percent efficiencies, based upon the AGI-30, were affected by the organisms studied. For *S. marcescens*, for example, the LVAS has a 95% efficiency rating compared to 90% for the MSI. Conversely, with *B. subtilus* var. *niger*, the LVAS was 74% and the MSI was 86% as efficient as the AGI-30 (44). Other studies have shown electrostatic precipitation to be less effective than liquid impingement for detecting viable airborne viruses (43,47). Such observations have been attributed to electrostatic precipitator-generated ozone (43), or to rapid evaporation of polar liquids, enhanced by electric current, or by a critical concentration of unipolar air ions (48).

The LVAS has been found to be effective for bacterial, viral and rickettsial aerosols when conventional sampling was not suitable, as with very dilute concentrations, and is most effective in still air when operated in a level position, constantly monitored by a trained technician, and not subjected to electric current fluctuations (49). In addition to being difficult to sterilize by conventional methods, problems with sampling fluid evaporation and quantitation exist with the large volume air samplers (50).

Cyclone scrubbing

The viable microbial aerosol cyclone scrubber samplers (Figure 5) collect airborne particles by tangential impingement into a continuous fine fluid film created as a mist is impacted into the sampler wall. The fluid film travels spirally to a reservoir where it is collected by slight suction. Such devices, constructed of glass, plastic, or stainless steel, have air sampling rates up to about 0.95 m^3/min and fluid flow rates from 1 to 4 ml/min (23,44,51,52). The scrubbing liquid, supplied either by peristaltic or screw-driven syringe pumps, is subject to water loss due to evaporation which may require replacement.

Available data (Figure 6) demonstrate that cyclone scrubber efficiencies are variable and dependent upon aerosol particle size, specific test organism, and collection fluid (52). Average efficiencies (AG1-30 reference) are reported to be 63% to 133% for *B. subtilus* var. *niger*, depending upon sampler configuration, particle size, and collecting fluid. Vegetative bacteria are more sensitive to collecting fluid composition variations than are bacterial spores. While 0.06% Tween 80 solution enabled relatively high recovery efficiencies for *B. subtilus* var. *niger* spores (23), for example, it was found to be toxic to the *S. marcescens* and *Escherichia coli* collected in a reference AG1-30 (52). Cyclone scrubber samplers lend themselves to sterilization by conventional processes and have been used in field studies for recovery of wastewater-generated viral aerosols (53). In the field, cyclone scrubbers are relatively easy to operate, compared to other existing large volume air samplers, but may require continual monitoring and fluid adjustments during sample collection.

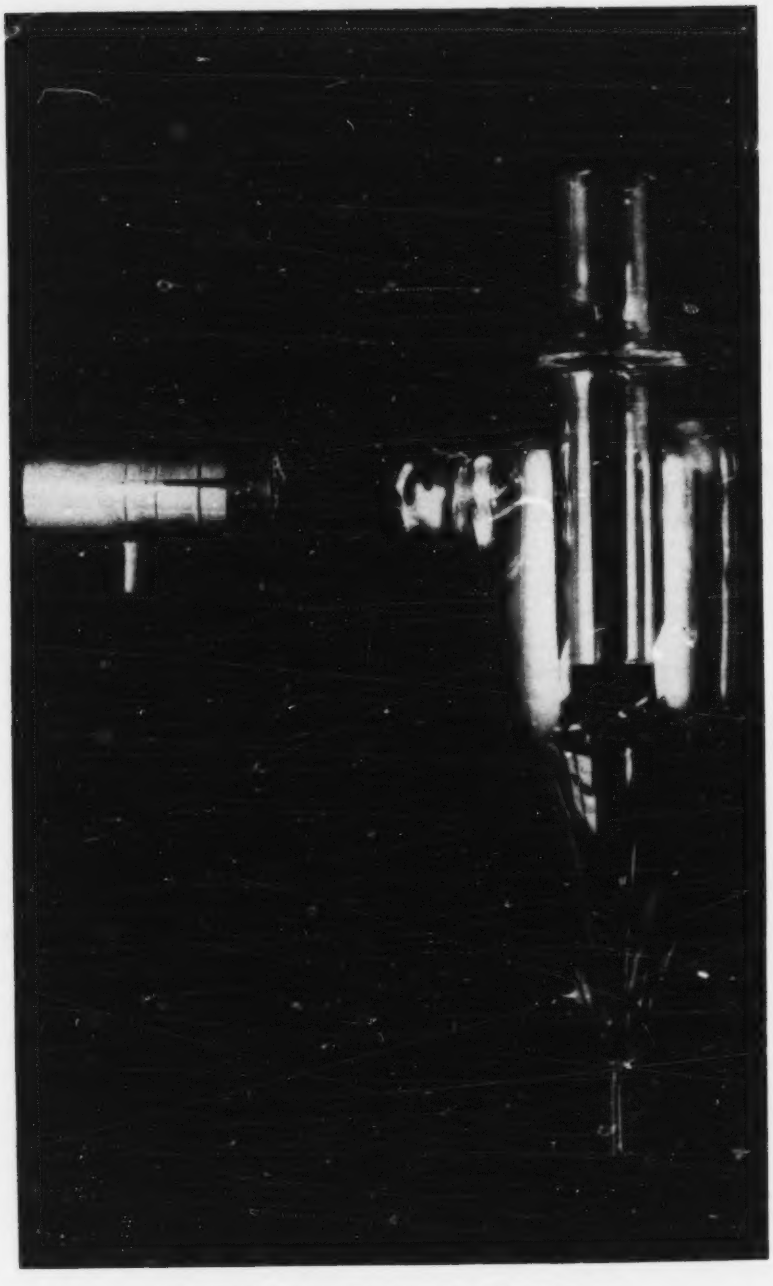


Figure 5. Glass Cyclone Scrubber Sampler

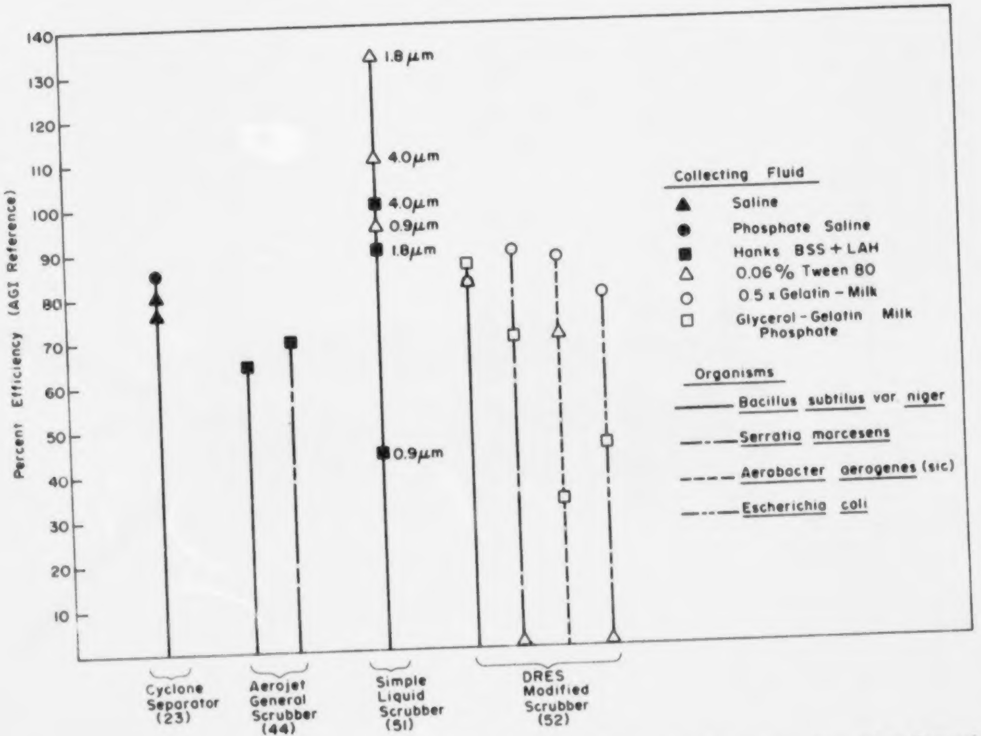


Figure 6. Microbial Aerosol Recovery Efficiencies with Four Cyclone Scrubber Samplers

Impaction

After acceleration to sufficient inertia to leave an airstream, aerosol particles can be impacted onto a collecting medium surface. This concept is used for simultaneous sampling and size analyses with the cascade impacter (54). This device, consisting of a series of four jets and slides, accelerates the aerosol with progressively smaller jets, permitting collection of progressively finer particles. Subsequent modifications of the cascade impactor have been used for collecting and sizing both bacterial and viral aerosols (55,56) (Figure 7). Acceleration through slits or jets of critical size and distance from the impaction surface is widely used for collection of microbial aerosols onto agar media. Examples of such devices include slit (Figure 8) and multistaged impactors (Figure 9). The most common forms of both instruments sample at a rate of about

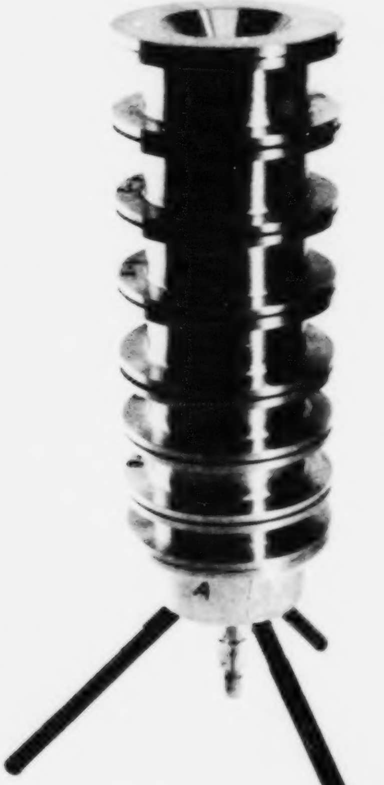


Figure 7. Modified Cascade Impactor

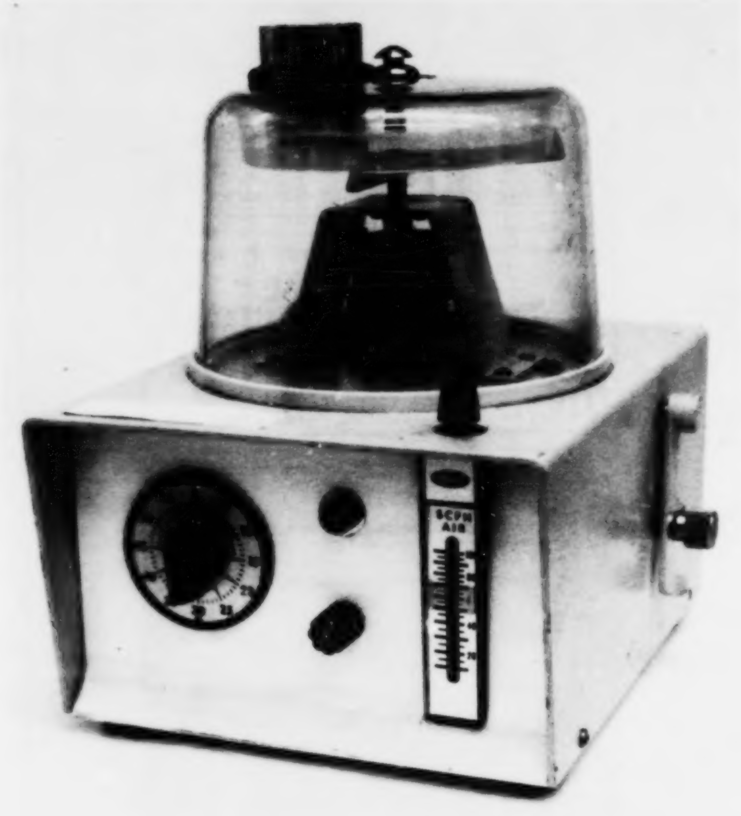
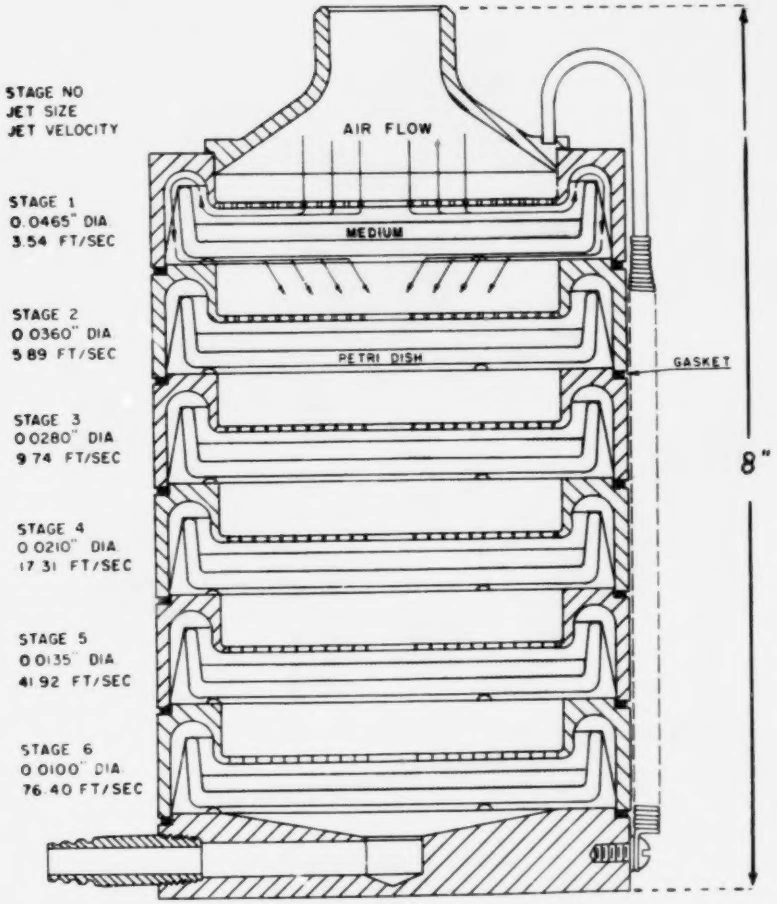


Figure 8. Slit Sampler

$0.028\ m^3/min$. With the slit sampler, airborne particles are collected onto a slowly rotating agar surface for time discrimination of microbial aerosol concentrations (57,58) while the multistaged impactor, such as that developed by Andersen (59), permits aerodynamic particle sizing by impaction onto the surface of staged agar-containing plates at increasing velocities. Wide acceptance of this multistaged impactor led to its recommendation as a standard sampler for collection of airborne microorganism-containing particles (13).

The sampling capacity of both the slit sampler and multistaged impactor is limited by their relatively low air sampling rates and by observations of decreased collected organism viability during prolonged sampling periods (60,61). The sampling period in both samplers can be extended without affecting the viability of collected organisms by applying an evaporation retardant to the agar surface (62). To further increase the air sampling capacity of agar impactors, larger volume instruments


STAGE NO
JET SIZE
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AIR FLOW
STAGE 1
0.0465" DIA
3.54 FT/SEC
MEDIUM
STAGE 2
0.0360" DIA
5.89 FT/SEC
PETRI DISH
GASKET
STAGE 3
0.0280" DIA
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STAGE 4
0.0210" DIA
17.31 FT/SEC
STAGE 5
0.0135" DIA
41.92 FT/SEC
STAGE 6
0.0100" DIA
76.40 FT/SEC

Figure 9. Andersen Multistaged Impactor Sampler

have been developed. The Cassella multi-slit impactor, designed for sampling up to 0.7 m^3/min and the Pagoda multistaged impactor, reported capable of sampling particles into distinct size ranges at rates up to 1 m^3/min, were described by May (63).

Modifications of agar impactor samplers for field sampling have stressed the importance of inlet design and alignment relative to the wind. Inlet removal, redesign of the jet pattern, addition of another stage, and horizontal alignment of the multistaged impactor have, for example, been recommended (64). A slit sampler designed to sample horizontally into the wind with tolerable deviation from isokinetic sampling at windspeeds up to 10 m/sec with an air sampling rate of 0.02 m^3/min was described (61). A major disadvantage of these field-modified samplers is that they still lack the sensitivity required for very dilute microbial aerosol concentrations. A major limitation of agar impactor samplers in general is that they are best suited for enumeration of microorganism-containing particles rather than for total bacteria or viruses, for which a liquid medium would be better suited.

Sampler Selection

Depending upon the objectives of the particular study, several types of samplers may be required for simultaneous sampling. If, for example, high sensitivity as well as particle size and time discrimination are required, such devices as large volume air samplers, multistaged impactors, and slit samplers may be employed. In practice, each sampler has unique advantages and disadvantages which should be considered prior to sampler selection or data interpretation. Prior to selecting specific sampling methodologies, consideration should be given to criteria such as: (1) collection efficiency; (2) sampling sensitivity; (3) reliability; (4) ease of sterilization; (5) maintenance of collected sample viability; (6) ease of sample assay; (7) ease of operation; (8) remote operation capability; (9) particle size discrimination; and (10) cost. Using these criteria, a sampler can be evaluated to determine its applicability for a specific field study.

Conventional aerobiological sampler evaluations, performed by relative rather than absolute methods, determine microbial aerosol collection efficiencies as a percentage of that observed in a reference sampler. The sensitivity of a particular sampler is directly related to its collection efficiency and to other operational parameters. The sensitivity of various samplers under specified conditions can be compared by determining a value which could be referred to as a coefficient of sensitivity defined as:

$$CS = \frac{CE \times R \times D}{V}$$

where:
CS = coefficient of sensitivity
CE = collection efficiency (% of reference sampler)
R = air sampling rate (m^3/min)
D = sampling duration capability (min)
V = final volume of collection medium (ml).

The CS value increases with collection efficiency, air sampling rate, sampling duration capability, and with reductions in the final collection fluid volume required for assay. One way to reduce this final collection fluid volume is recirculation during the sampling process. Depending upon the organisms collected, however, such a practice could result in some viability losses which would, in turn, reduce the estimated viable microorganism collection efficiency.

The reliability, ease of sterilization, ease of operation, and remote operation capacity vary substantially among existing viable microbial aerosol samplers. Sampler reliability, which is related to the dependability and robustness of individual components, is of critical importance in the field when replacement parts and repair services are not available. Samplers designed with heat-sensitive components integrally associated with aerosol collection or sample moving systems do not lend themselves to sterilization by conventional steam autoclaving procedures and may require the selection and evaluation of other means of sterilization. Independent sampler operation during field studies requires varying degrees of operator training. Such devices as slit samplers, for example, are relatively simple to operate compared to electrostatic precipitator large volume air samplers and, consequently, require substantially less intensive personnel training prior to field use. Although, in practice, most viable microbial samplers require some attention in the field, those with greater remote operation capacity offer more versatility for field use than those which require constant attention.

The kind of sampler chosen depends upon the study objectives and the assay procedures. If, for example, an objective is to assess risks of respiratory infections, then a sampler classifying the microbial aerosol according to particle size should be employed. Although agar-based samples are easy to assay for certain kinds of bacteria or fungi, samplers employing a liquid collecting medium permit versatility by enabling both sample dilutions and greater assay technique versatility. Bacteria and viruses, for example, may be assayed from the same liquid medium sample. During sample collection, transport, and assay, an environment compatible with the survival of specific kinds of organisms should be employed. Generally, this requires continuous hydration of the organisms in a collection medium at a temperature compatible with organism survival, but not growth.

The cost of viable microbial aerosol samplers varies substantially. Glass impinger samplers are, for example, inexpensive while the cost of certain large volume electrostatic precipitators is relatively high. When resource limitations are a factor, relative costs must be considered in the sampler selection process.

FIELD STUDY IMPLEMENTATION

Field Sampling

All sample and data analyses, interpretations, and conclusions are dependent upon the reliability and validity of the sample collection process. If the sampling process is questionable, then subsequent analyses and inferences may be meaningless. Collection of an accurate and representative air sample can be a very complicated task requiring participating personnel who are both versatile and dedicated, having some mechanical aptitude as well as basic training in applied microbiology and air sampling methods.

Along with the problems of selecting instrumentation and personnel, the procedures employed in the field must be carefully planned. If resources are limited, a smaller number of sensitive samples may be of greater value to project objectives than a large number of insensitive samples. The representativeness of a particular sample will be affected by air sampling velocities, sampler inlet orientation, and windspeed and direction fluctuations. Under normal ambient conditions, isokinetic sampling is very difficult and impractical to achieve (54). In addition to sample collection difficulties, other logistical problems such as electrical supply requirements, frequent sampler breakdowns in the field, maintaining sampler sterility, field communication, transportation of sampling equipment at the field site, and transport of collected samples to the laboratory for assay have been noted (11) and must be considered. Sample handling during the sampling process and transport to the laboratory for assay must be done to minimize the possibility of contamination and microbial die-off or growth.

Sample Assay and Enumeration

When available, standard procedures should be employed for the assay of specific microbiological parameters (65,66). Precise methods for sample analyses are affected by sampling fluid composition and required detection sensitivities. Samples collected on an agar-based medium, for example, may only require incubation prior to enumeration whereas those collected in a liquid medium may, depending on the test organism, require simple dilution and plating, filtration, or elaborate processing procedures prior to assay.

Microbial aerosol concentrations are expressed as detectable assay units/m³ of air. Enumeration can be based upon direct counts or multiple tube dilution methods, such as the most probable number (mpn) procedures, for estimation of the number of detectable assay units per sample volume. Application of multiple tube dilution procedures has been shown, in some instances, to be more sensitive than direct enumeration methods for detecting certain microorganisms (67). Selection of specific enumeration procedures, however, may be based upon specific project objectives, assay methods, and sensitivity requirements.

Microbial aerosol concentrations from fluid medium samplers can be determined by:

$$C = \frac{N}{A} \times \frac{V}{R \times D}$$

where:

C = concentration of detectable microbial units/m³ air (e.g., cfu/m³)
N = number of detectable microbial units (e.g., cfu, mpn pfu)
A = portion of sample assayed (ml)
V = final volume of collection fluid (ml)
R = air sampling rate (m³/min)
D = sampling duration (min).

For agar-based medium samplers, A and V may be omitted unless only a portion of the total sample is to be counted. In such a case, the volume of air/cm² agar surface are would be used in concentration calculations. If the sampler collection efficiency is known, then the C value should be appropriately corrected.

Quality Assurance

Methods for detecting viable microbial aerosols are not yet standardized. Consequently, there may be considerable variation between the results among investigators using different sampling or assay procedures. The efficiency of viable microbial air samplers depends upon a number of operational parameters, including air sampling and fluid flow rates, wind velocity and direction fluctuations, aerosol particle size and density variations, as well as the overall efficiency of the sampler itself. The efficiency of specific samplers may be determined relative to a reference sampler under experimental conditions for aerosols having known characteristics. Such determinations, however, are relative and not absolute. Under varying conditions, such as those encountered in the field, true sampling efficiencies cannot easily be ascertained.

Prior to use and periodically throughout the project, each sampler should be calibrated to determine air flow rates using a precalibrated mass flow meter or anemometer. All samplers should be numbered and each collected sample identified with a particular instrument. Controls for verification of field sampler sterility and laboratory assay procedures should be employed where appropriate. In addition to quality assurance procedures required for the specific project, recommended laboratory and assay procedures (65, 66) should be adhered to where applicable.

Data Analyses and Interpretation

Data from a field study of microbial aerosol concentrations may be collected under a wide range of meteorological conditions, each having effects on microbial survival, dispersion of heterogeneously-sized aerosols, and aerosol sampling efficiencies that may be either known or unknown to the investigator. The validity of statistical analyses of such data requires that basic underlying assumptions, such as homoscedasticity and normality of the test populations, be met. If such assumptions can neither be verified nor assumed because of uncontrolled field study variables, then alternatives to conventional parametric analysis should be considered. Data interpretation must take into account the limitations of the methodologies employed to obtain the information.

ACKNOWLEDGEMENT

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DISCUSSION

MR. JAKUBOWSKI: The sensitivity of the concentrating method seems to be a key item for interpreting biologic and epidemiologic data. It seems that we do not have clear guidelines on how we can arrive at acceptable sensitivity. I wonder if you would care to offer any comments on how we can arrive at what would be an acceptable level of sensitivity?

DR. FANNIN: My comment was that I haven't arrived at an acceptable sensitivity, but I suggested that this be based upon exposure, either to a population or to an individual, over a limited time period. This is a very difficult problem. If we are sampling something by using a teaspoon that may require use of a bucket, we have to evaluate what that sample from a teaspoon actually means.

The important thing is to evaluate what a low level concentration means to a population. I am not prepared to make a statement as to what is an acceptable concentration of specific organisms.

DR. FLIERMANS: I think it is important, if you are talking about sampling, to talk about methods for detecting organisms. I think that is a mutually important aspect. One has to consider all methods. Indirect methods, that is, plating the organisms on some kind of medium, inhibits other organisms and may even inhibit the ones that you are dealing with. Would you care to comment on some of the direct methods?

DR. FANNIN: By direct procedures, what are you referring to?

DR. FLIERMANS: I am referring to things like fluorescence, looking at total numbers, looking for specific organisms that you are dealing with. The sensivitity to these kinds of things could be very low.

DR. FANNIN: I am familiar with these methods, and I am also aware that these have been used in other investigations. Primarily, to my knowledge, much of the effort has been related to detecting viable organisms as determined by their ability to grow, rather than detecting the antigen itself in the sample.

I acknowledge that this is a very effective method of detecting organisms.

MR. WITHAM: Was your study based on any of your own data?

DR. FANNIN: This is an overview, a presentation of various methods as an introduction to this particular symposium. It is not based upon our data.

DR. WITHAM: Have you actually come across a sampler with which you can unequivocally collect viral data?

DR. FANNIN: Yes. The use of a sampler is dependent upon the concentration of the viruses in the aerosol, but there are many samplers which have been demonstrated to be quite effective in the collection of virus. Yes, that is not a difficult task, but at very low level concentrations it becomes a difficult task.

DR. SCHAUB: Thank you very much, Dr. Fannin. That was a most interesting presentation. I think that it increases everyone's awareness of the potential problems in dealing with sampling of aerosols, a very sophisticated and complex problem, and there is still a lot of work that needs to be done on it before we can really come up with some totally satisfactory conclusions about the efficacy of aerosol sampling.

Indicators and Pathogens in Wastewater Aerosols and Factors Affecting Survivability

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ABSTRACT

This paper attempts to consolidate the information available on wastewater microbiological aerosols. Organisms of concern which have been isolated from wastewater are identified. Where available, information on their probable survival in aerosols is presented. Data is evaluated as to the relative survival rates of pathogens and traditional indicator organisms. Further, the paper delineates those areas where more work is required, for example in the identification and selection of (an) appropriate organism(s) and sampling methods permitting routine monitoring of wastewater aerosols in cases where this is considered necessary.

The potential health effects of wastewater aerosols continue to be of concern, based both on the numbers of pathogens found in wastewater and on still inadequate information on minimal infectious doses of those pathogens, particularly viruses. This concern has been exacerbated by the increasing trend to operate wastewater land application facilities in populated areas, especially as urban sprawl continues to engulf existing conventional treatment facilities.

Studies seeking to resolve some of the questions regarding aerosolized wastewater have addressed, in turn, the concentration and fate of pathogens in sewage, the effect of various wastewater treatment unit processes on the organisms of concern, the amount of wastewater aerosolized, the immediate effect of aerosolization on the organisms (aerosol shock or aerosol impact), and the biological decay of the organisms during transport as aerosols. As knowledge of the concentration and extent of the transport of these organisms has increased, greater emphasis now must be placed on the more difficult question: What is the level of risk associated with various concentrations of these aerosols?

This paper seeks to consolidate, in review form, the information available on wastewater microbiological aerosols. It attempts to evaluate the factors which affect the survival of aerosolized microbes, with particular attention to their potential health effects. Field data are considered in an effort to identify one or more indicator organisms to be used in monitoring wastewater aerosols.

PATHOGENS IN WASTEWATER

The concentration of microorganisms in domestic sewage is influenced by a complex of several factors including demography as well as seasonality. The array of potentially pathogenic microorganisms encompasses bacteria, helminthic parasites, protozoans, and viruses (Table 1). The presence and survival of these major groups of pathogens in wastewater have been reviewed by Foster and Engelbrecht (1), and more recently, Akin and his associates (2), and Sproul (3). Whereas pathogenic organisms such as *Salmonella typhosa* have a relatively short survival time in wastewater, other pathogens, including *Mycobacterium spp.*, *Ascaris* ova, and certain enteric viruses, appear to be highly resistant to environmental stress.

Table 1. Selected Organisms of Health Concern That May Be Present in Sewage from U.S. Communities (2)

Organisms	Disease	Reservoir(s)
Bacteria:		
Salmonella (Approx. 1,700 types)	Typhoid fever Salmonellosis	Man, domestic and wild animals, and birds
Shigella (4 spp.)	Shigellosis (bacillary dysentery)	Man
Escherichia coli (enteropathogenic types)	Gastroenteritis	Man, domestic animals
Enteric viruses:		
Enteroviruses (67 types)	Gastroenteritis, heart anomalies, meningitis, others	Man, possibly lower animals
Rotaviruses	Gastroenteritis	Man, domestic animals
Parvovirus-like agents (at least 2 types)	Gastroenteritis	Man
Hepatitis A virus	Infectious hepatitis	Man, other primates
Adenoviruses (31 types)	Respiratory disease, conjunctivitis, others	Man
Protozoa:		
Balantidium coli	Balantidiasis	Man, swine
Entamoeba histolytica	Amebiasis	Man
Giardia lamblia	Giardiasis	Man, domestic and wild animals
Helminths:		
Nematodes (Roundworms)		
Ascaris lumbricoides	Ascariasis	Man, swine?
Ancylostoma duodenale	Ancylostomiasis	Man
Necator americanus	Necatonasis	Man
Ancylostoma braziliense (cat hookworm)	Cutaneous larva migrans	Cat
Ancylostoma caninum (dog hookworm)	Cutaneous larva migrans	Dog
Enterobius vermicularis (pinworm)	Enterobiasis	Man
Strongyloides stercoralis (threadworm)	Strongyloidiasis	Man, dog
Toxocara cati (cat roundworm)	Visceral larva migrans	Carnivores
Toxocara canis (dog roundworm)	Visceral larva migrans	Carnivores
Trichuris trichiura (whipworm)	Trichuriasis	Man
Cestodes (tapeworms)		
Taenia saginata (beef tapeworm)	Taeniasis	Man
Taenia solium (pork tapeworm)	Taeniasis	Man
Hymenolepis nana (dwarf tapeworm)	Taeniasis	Man, rat
Echinococcus granulosus (dog tapeworm)	Unilocular echinococcosis	Dog
Echinococcus multilocularis	Alveolar hydatid disease	Dog, carnivore

Table 2. Removal of Organisms by Conventional Wastewater Treatment (3)

Treatment	Agent	Removal (%)	Test System
Plain sedimentation	Viruses:		
	Polio 1	0	bench
		* to 69	plant
	Polio 1, 2, 3	0–12	plant
	Parasites:		
	Beef tapeworm eggs	50	bench
	E. histolytica cysts	0 to *	plant
	Bacteria:		
	Mycobacterium tuberculosis	50	plant
	Coliform	27-96	bench
Trickling filters	Viruses:		
	Coxsackie A9	94	bench
	Echovirus 12	83	bench
	Polio 1	85	bench
	Mixed (natural)	* to 69	plant
	Parasites:		
	Beef tapeworms eggs	30	bench
	E. histolytica cysts	*	plant
		90-99.9	bench
	Bacteria:		
	Mycobacterium tuberculosis	45	plant
	S. typhosa	72	plant
	Coliform	98	plant
	Ps. aeruginosa	+74 (increase)	plant
	Cl. perfringens	92	plant
Activated sludge	Viruses:		
	Coxsackie A9	96-99	bench
	Polio 1	79-94	bench
	Mixed (native)	53-71	plant
	Polio 1, 2, 3	76-90	plant
	Parasites:		
	Beef tapeworm eggs	0	bench
	E. histolytica cysts	*	plant
	Bacteria:		
	Salmonella typhosa	86-99	bench
	Vibrio cholera	96-100	bench
	Mycobacterium tuberculosis	90+	bench
	Coliform	97	bench
	Fecal Streptococci	96	bench

* Incomplete

Several papers have explored various aspects of the potential public health effects of wastewater treatment processes (1-9). However, before a rational assessment can be made regarding the degree of health risk posed by wastewater aerosols, the fate and distribution of pathogenic and indicator microorganisms between the solid and liquid phases of wastewater as a function of wastewater treatment must be considered (Table 2). Primary treatment alone does not significantly reduce the pathogen load in domestic wastewater, although primary sludges may contain large numbers of parasite eggs. The sludge biomass generated by conventional secondary treatment, however, may be expected to contain a major portion of that microbial population which has been removed from the incoming wastewater.

Table 3. Results of Bacterial Screens at Several Wastewater Treatment Facilities

	(cfu/100 ml)			
	Pleasanton[a]	Portland[b]	Chicago[b]	Kerrville[a]
Citrobacter	$<5.0 \times 10^{-1}$	6.6×10^{3}	$<3.0 \times 10^{2c}$	$>6.7 \times 10^{3}$
Clostridium	2.8×10^{2}	—	1.5×10^{2}	—
Edwardsiella	$<5.0 \times 10^{-1}$	—	$<3.0 \times 10^{2c}$	—
Enterobacter	3.0×10^{5}	5.0×10^{4}	2.0×10^{4}	$>1.2 \times 10^{4}$
Escherichia	1.0×10^{6d}	6.7×10^{3}	$<3.0 \times 10^{2c}$	5.3×10^{3}
Klebsiella	6.0×10^{4}	3.7×10^{4}	1.0×10^{5}	1.4×10^{4}
Leptospira	4.6×10^{3}	—	2.4×10^{2}	—
Mycobacterium	7.0×10^{4}	1.3×10^{6}	1.3×10^{5}	1.0×10^{2}
Providencia	1.0×10^{4}	$<3.3 \times 10^{0}$	$<3.0 \times 10^{2c}$	c
Serratia	$<5.0 \times 10^{-1}$	6.6×10^{2}	$<3.0 \times 10^{2c}$	6.7×10^{2}
Staphylococcus	3.0×10^{3}	3.3×10^{3}	2.0×10^{6}	8.7×10^{3}
Fecal coliform	1.0×10^{7}	5.3×10^{4}	1.0×10^{6}	8.1×10^{4}
Total coliform	1.1×10^{8}	1.8×10^{5}	3.7×10^{6}	1.4×10^{5}
Total plate count	5.8×10^{9}	4.8×10^{8}	8.2×10^{8}	—

[a] Ponded secondary effluent
[b] Aeration basin
[c] None detected

Analyses in our laboratory of several large-volume samples from wastewater treatment facilities have yielded confirmed isolates of species of *Clostridium, Enterobacter, Escherichia, Klebsiella, Leptospira, Mycobacterium, Providencia*, and *Staphylococcus* as shown in Table 3. It should be noted that the levels of these organisms vary considerably. Bacterial pathogen concentrations in treated wastewater have been reported over a wide range. Tables 3 and 4 provide examples of the relative numbers of selected pathogens and indicator organisms from recent field studies. The data in Table 4 were from a very extensive study which investigated a secondary wastewater treatment plant effluent used in spray irrigation (10). Similar data have been developed for aeration basins at operating activated sludge treatment facilities (11,12).

Table 4. Relative Numbers of Selected Microorganisms in the Effluent Wastewater Samples (10)

Microbiological parameter	Concentration units	Geometric mean	Ratio of total coliform
Standard plate count	No./ml	699,000	93.4
Total coliform	mfc/ml	7,480	1.000
Pseudomonas	cfu/ml	1,050	0.140
Fecal coliform	mfc/ml	795	0.106
Klebsiella	cfu/ml	388	0.052
Coliphage	pfu/ml	224	0.030
Streptococci	cfu/ml	67.3	0.009
Clostridium perfringens	mpn/ml	53.9	0.007
Enteric viruses (5 day)	pfu/ml	0.017	0.000002

The numbers of viruses reported in domestic wastewaters also vary widely and will depend on the virus-detection techniques employed.

Shuval (13) reported average effluent recoveries for different communities from about 500 plaque forming units (pfu)/l to over 1600 pfu/l. Other reports have indicated concentrations of up to 7000 PFU/l for raw sewage to about 50 pfu/l for chlorinated secondary effluent (8,14).

Concentration of the microbial population into the secondary biomass makes it essential to implement sludge-processing practices that can diminish the concentrations of pathogenic bacteria, of helminth ova, and of viruses. Anaerobic sludge digestion, aerobic sludge stabilization, lime stabilization, composting, and sludge lagooning are among the more popular methods for treating waste sludges. A summary of treatment effectiveness of some of these processes in pathogen removal can be found in Table 5.

An Environmental Protection Agency report on microbial survival during anaerobic digestion indicated that while coliform populations are reduced greatly, other pathogens, such as *Mycobacterium* and *Ascaris* ova, can withstand prolonged digestion (16). Several laboratory studies have reported the fate of selected viruses during anaerobic digestion (17,18). Inactivation rates ranged from 74.9%/day for Echovirus 11 to 90%/day for poliovirus to 97%/day for Coxsackievirus A-9 using added free test viruses. Much slower rates were observed using solids-incorporated poliovirus (19). While significant pathogen reductions can be achieved by anaerobic digestion, actual field digesters appear to be less efficient, owing, undoubtedly, to the continuous input of contaminated raw sludges coupled with probable short-circuiting and incomplete mixing (20).

Table 5. Municipal Wastewater Treatment Plant Inactivation of Pathogens in Sludges (15)

Treatment	Range of Effectiveness
Lime	Kills pathogenic bacteria; highly effective at high pH (>11.5)
Heat—pasteurization	Destroys pathogens at 70°C for 1/2 to 1 hour
Composting	Mechanical: pathogen-free after 1 day; spores 1 week Contour: pathogen free after 1 week
Anaerobic digestion	Bacteria: reduced at approximately natural die-off rate Helminth ova: at least 1 month for destruction Cysts: destroyed in 10 days at 30°C Virus: some survive long periods
Aerobic digestion	Reduces pathogens to low numbers

Generally, disinfection (specifically chlorination) of effluents before discharge provides the last step in the treatment scheme. Difficulties arise in comparing published results of chlorination studies because of a lack of specific information on initial chlorine dosage, reaction temperature, pH, and the level of organic or inorganic nitrogenous compounds present. Selected microorganisms, including some species of *Mycobac-*

terium, amebic cysts, and certain enteric viruses (among them the agent of waterborne hepatitis), are reported to be more chlorine-resistant than are indicator coliform organisms (3).

Thus, the treatment train, without disinfection of the effluent, can be relatively effective in reducing the levels of most microorganisms. It is probable, however, that biological treatment leaves not less than 1 to 10% of *Salmonella*, *Mycobacterium* and some human enteric viruses in the wastewater effluent.

WASTEWATER AEROSOLS

Those particles in the size range 0.01 to more than $50 \mu m$, which are suspended in air, are defined as aerosols. Potentially pathogenic aerosols are generated as a result of the physical processes of aerating, trickling, and spraying wastewaters and sludges. The density of microorganisms in aerosols is a function of the density of a specific organism in the wastewater, aeration basin, or sludge; the amount of material aerosolized; the effect of aerosol shock (impact); and, finally, biological decay of the organisms with distance in the downwind direction (8,11,21,22).

A number of studies have been conducted in an attempt to identify quantitatively the levels of microorganisms emitted in aerosols generated by wastewater spray irrigation and other wastewater treatment processes (11,21-30). In attempting to interpret these data an important consideration is the quantity of a particular pathogen required to initiate an infection in individuals. This probably is the most difficult factor to assess. Over the past few years, quantitative procedures for enumerating pathogen levels in aerosols have been developed. Unfortunately, equally sensitive real-time epidemiological procedures have not kept pace. Recently, Pipes (31) edited a volume containing a summary of published infectivity data for several pathogenic bacteria and for poliovirus vaccine. These data, in part, are derived from studies using laboratory strains in healthy volunteers. As such, they may have limited relevance to the problem under discussion here.

Factors Affecting Survival

Aerosol Impact

Immediately after aerosolization, numerous environmental factors have an impact on the viability of aerosolized organisms. The individual effects of relative humidity, temperature, and sunlight, on selected organisms, have been described elsewhere (8). These initial die-off factors in the aggregate have been referred to as aerosol shock or aerosol impact.

In an early study on bacterial aerosols at a spray irrigation site, the initial impact factors were reported to contribute to a 0.5 $\log_{10}$ loss in concentration of the test bacterial group (26). In another study using exogenously introduced f_2 bacteriophage, similar results were observed (21). A recent, more definitive study explored a wider range of pathogens and indicator organisms (27,32). The relative aerosolization survival (the relative importance of initial aerosol shock) for these organisms is presented in Table 6 for each microbiological entity measured. The ratio of the aerosol to wastewater population concentrations at the 5

Table 6. Geometric Means and Ratios of Wastewater and Aerosol Concentrations of Microbiological Parameters (32)

	Geometric Mean Wastewater Conc. (no./ml)	Geometric Mean Aerosol Concentrations (no./m³ of Air)			Aerosol/Wastewater Ratio of Geometric Mean Concentrations	
		Upwind	Downwind		Downwind	
FIRST RUNS			*5-20 m*	*100-200 m*	*5-20 m*	*100-200 m*
Standard plate count	699,000	805	2,570	880	0.0037	0.0013
Total coliform	7,500	< 0.5	5.7	1.2	0.0008	0.0002
Fecal coliform	800	< 0.3	1.0	< 0.3	0.0013	< 0.0004
Coliphage	220	< 0.1	0.34	0.18	0.0012	0.0006
Fecal streptococci	67	< 0.6	1.4	1.9	0.021	0.028
Pseudomonas	1,050	< 15	72	43	0.068	0.011
Klebsiella	390	< 5	< 5	< 5	< 0.01	< 0.01
Clostridium perfringens	54	< 0.9	1.5	1.1	0.027	0.020
		Upwind	Downwind		Downwind	
SECOND RUNS			*50 m*	*100 m*	*50 m*	*100 m*
Standard plate count	150,000	300	450	330	0.0028	0.0021
Total coliform	4,900	< 0.2	2.52	0.59	0.0005	0.0001
Coliphage	290	< 0.1	0.51	0.23	0.0017	0.0008
Fecal streptococci	34	0.15	0.34	0.29	0.0100	0.0085
Mycobacteria	46	0.30	0.80	0.82	0.0176	0.0178
Enterovirus	0.12		0.014		0.11	

to 20 m distance should indicate the relative survival of the microbes through the initial environmental impact associated with aerosolization. Most of the pathogenic bacteria (*Pseudomonas*, *Streptococcus*, *Clostridium perfringens*, *Mycobacterium*) were substantially less affected by the initial aerosol shock than were the indicator organisms and coliphage. *Klebsiella* was found to be more subject to initial shock than were the other pathogenic bacteria. However, the absolute extent of its susceptibility is not known because the aerosol concentration of this genus was below detection limits. Enteroviruses (at 50 m) were found to be least affected by aerosol shock (27).

Biological Decay

Several factors contribute to biological die-off or decay, including ultraviolet radiation, temperature, and relative humidity. The relative magnitude of biological decay or microbiological depletion with distance from the aerosol source has been evaluated. This was accomplished by first normalizing the observed aerosol microorganism concentration using the source concentration for a particular organism. The mean close-downwind (5 to 20 m) aerosol concentration of that organism can give a reasonable estimate (post aerosol impact) of the aerosol concentration at

20 m from the wet-line edge. The rate of microbiological decay can be obtained by determining the change between the close-downwind concentration and that of some further downwind point, for example 100 m.

This technique was applied to four representative microbiological measurements (standard plate count, total coliform, *Pseudomonas*, fecal *Streptococcus*). The standard plate count and total coliform parameters exhibited a rate of microbiological decay that was quite rapid, amounting to about one order of magnitude in 100 m for total coliform and about half an order of magnitude in 100 m for a standard plate count. The latter corresponds to previously published data (26). There was virtually no effect on *Pseudomonas*, and the decay of fecal *Streptococcus* with distance was very slight.

As a methodology for detecting low levels of enteric viruses in wastewater aerosols has only recently been described (33), the aerosolized level for these viruses was obtained at only one distance (50 m) and for only two samples. Therefore, the calculation of decay was not possible (27). However, significant decay for enteric viruses is considered unlikely at any reasonable distance from the spray source.

Indicator Organisms

Another consideration in the overall evaluation of field data is the choice of an indicator organism. This can be approached by evaluating the ratio of indicator organisms to pathogenic organisms. After adjusting the data from one extensive field study to common units, this comparison was made (27). Table 4 presents the ratio of each parameter's geometric mean to the total coliform geometric mean. The four selected pathogenic bacteria, fecal coliform, and coliphage all lie within one and one-half orders of magnitude of each other. The observed virus concentrations in the effluent samples were at least three orders of magnitude less than those of any bacterial pathogen.

Wastewater monitoring for potential microbiological health hazards traditionally focuses on the concentrations of indicator organisms, such as total coliforms, fecal coliforms, and the standard plate count. These easily-assayed microbial groups are plentiful in domestic wastewater. The presence of fecal coliforms in the aquatic environment is considered as indicative of the possible presence of associated pathogenic bacteria and human viruses (Table 7). The pathogens are themselves difficult to assay and seldom occur at readily detectable concentrations. Thus, the substantially higher concentrations of total coliform and standard plate count found in the aeration basins (relative to the effluent ponds) are taken to indicate the existence of relatively higher aeration basin concentrations of pathogens such as human enteroviruses, *Klebsiella*, *Pseudomonas*, *Mycobacterium*, and fecal *Streptococcus*.

The sample data base in the study conducted at Pleasanton, California cited above (27), consisted of 47 daily effluent composite samples and seven grab samples. Summary statistics calculated for each of the ten indicator and pathogenic microbiological parameters can be found in Table 6. Various statistical techniques were used to evaluate these data, and in each case very poor correlation was shown between the patho-

Table 7. Waterborne Outbreaks (1973-1976) Correlated With Indicator Bacteria Occurrences (31)

Caustive agent	Water supply	Indicator occurrence
Shigella	Richmond Heights, FL	Excessive fecal coliform
Salmonella typhosa	Homestead, FL	Excessive coliform
Toxigenic *E. coli*	Crator Lake Nat. Park, OR	Excessive coliform
Intestinal agent (not identified)	Girls camp in PA	324 fecal coliform/100 ml
Shigella	Church Camp in MI	Excessive fecal coliform
Intestinal agent (not identified)	Camp Grounds, ID	190 total coliform/100 ml
Shigella	River bathing area, Dubuque, IA	17,500 fecal coliform/100 ml

gens and any of the customary indicator organisms. On the other hand, there was good correlation between total coliform and fecal coliform.

The daily concentrations of each type of microorganism in the Pleasanton pond effluent varied at least tenfold and sometimes over one hundredfold during the study period. However, the observed changes in the traditional indicator organism concentrations had virtually no relation to the daily changes in the pathogen concentrations. Thus, the use of wastewater indicator organisms such as total coliform or fecal coliform for daily monitoring of effluent quality was inadequate as a means of detecting significant changes in bacterial pathogen concentrations. At the same time it does not appear from these data that coliphage would have been a good choice for monitoring viruses.

We hasten to note, however, that Fannin and his coworkers (29) have proposed the use of coliphages as indicators of aerosolization from wastewater treatment plants. From the data obtained by these researchers, it was suggested that one could estimate animal virus levels by use of coliphages. In a later paper, Fannin and his colleagues (34) concluded that wastewater treatment facilities could serve as a continuous source of low level animal virus aerosols. They noted that phages were more stable than coliforms in the airborne state and, therefore, more acceptable as indicators of airborne animal virus concentrations. That phages are more stable in wastewater aerosols than are members of the coliform group appears to be borne out by extensive field data; that their stability approaches that of human viruses has yet to be substantiated.

Engelbrecht and his associates (35-37) have been concerned with identifying an alternative to coliform bacteria as indicators of fecal contamination. They have found *Mycobacterium phlei, Mycobacterium avium*, and a yeast (*Candida parapsilos*) to be among the more promising candidate organisms. These organisms have been known to survive prolonged contact with disinfectants. The data presented in Table 6 suggest that *Mycobacterium* and fecal *Streptococcus* are quite hardy in wastewater aerosols as well.

In selecting an indicator organism one must consider, among other things, the ability of the organism to survive in the environment of concern (aerosolized wastewater or sludge), the relationship of level of indicator organism to pathogen concentration, and the ease and speed with which the presence of the organism can be determined quantitatively. Current data suggest that of all the proposed indicators, fecal *Streptococcus* most closely satisfies these criteria for aerosolized wastewaters.

SIGNIFICANCE OF DATA AND CONCLUSIONS

Unfortunately, there have been few studies conducted in the United States designed to evaluate the epidemiological significance of wastewater aerosols from a spray irrigation site. Obtaining quantitative aerosol data, together with the development of predictive models, provides only part of the necessary information. The next, and perhaps most important, step involves putting this information to direct use through determination of the effects of these aerosols on humans. Clark and his associates (38) have summarized the results thus far of an ongoing seroepidemiological study of treatment plant workers and obtained evidence only of increased subclinical viral infections. Workers exposed to dried wastewater dusts were reported by Mattsby and Rylander (39) to have higher incidences of work-related fevers, diarrhea, and other symptoms consistent with endotoxin exposure. Fannin and his coworkers (40), as reported by Kowal and Pahren (41) found increased risk of respiratory and gastrointestional illness in persons living within 600 m of an activated sludge wastewater treatment plant in Tecumseh, Michigan, but related this to socioeconomie factors. In contrast, no health hazards were detected by Johnson and his associates (12) for persons living beyond 400 m of a Chicago area wastewater treatment plant or for school children active within 100 m of a Portland area wastewater treatment plant (11).

Considerable question remains as to the level of risk to be associated with microbiological aerosols from wastewater treatment operations in the United States, including spray irrigation. These uncertainties are compounded by the dependence of the concentration of organisms in the aerosols upon the demographic and socioeconomic structure of the community, the type of wastewater treatment provided, the method of application, and the prevailing meteorological conditions. Data from several field studies suggest that of the potential indicator organisms, fecal *Streptococcus* may represent the most logical choice at this time for monitoring aerosolized wastewaters.

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DISCUSSION

MR. JAKUBOWSKI: The data that you presented on aerosol shock was derived as a result of spray irrigation. Is aerosol shock something that one would expect to occur in a wastewater treatment plant?

DR. SORBER: Certainly.

MR. JAKUBOWSKI: Is there any data available to indicate that aerosol shock is of the same magnitude as what is observed with spray irrigation?

DR. SORBER: David Camann might get into this in his modeling paper a little later. He just indicated that it has been difficult to separate the factors between the different places. We don't have the same kind of data for the wastewater treatment plant.

MR. JAKUBOWSKI: So you believe that the situation with regard to the standard indicators also holds up for aerosols in wastewater treatment plants and that there would be no correlation between indicators and pathogens?

DR. SORBER: I think that you can see that in the downwind data from the sewage treatment plant's aeration basins. The difficult problem is that with the aeration basins it is hard to identify that portion of the wastewater which has been aerosolized. The aerosolization efficiency component is not as readily obtainable from an aeration basin as it is from a spray source. In fact, I would think that it is far lower because of the design and construction of the aeration basin.

DR. WARD: I realize there are going to be a lot of possible indicators that people are going to be looking at for years. One of the most promising ones, as far as viruses go right now, comes out of the study that is being carried out at Utah State University by Dr. Rex Spendlove. This study concerns reoviruses, and it appears that it is probably the best virus indicator there is. The reason for this is that reovirus is found in the highest numbers by the method he uses to detect it. It is found consistently, throughout the year, in high numbers. Reovirus is hardier than the other viruses. So this indicator looks like a good one for future studies in wastewater. I think it would be good to have this kind of a study done with aerosol as well.

DR. SPENDLOVE: Rex Spendlove and I are working with a graduate student, Jack Adams, Ph.D., in the subject you just referred to. We are finding that the problem with reovirus is that it is very stable once it gets airborne, but it has a low aerosol efficiency. We get a lot of death immediately. I don't know how this compares to some of the other viruses, but once it is aerosolized it is very stable.

DR. LUND: I would like to know what evidence you have for aerosol shock?

DR. SORBER: The evidence is based on collection efficiency. It is a very good question. The evidence that we have is based on collection efficiencies of the samplers involved in aerosol chambers, not unlike some of the data that Dr. Fannin showed earlier in the first presentation. There has always been considerable question as to how efficient these samplers are.

DR. SCHAUB: I think that everybody can see that there are some problems with our basic group of indicator organisms, or at least potential problems. These organisms should be further examined to see whether or not they really typify the pathogens which are going to be associated with wastewater aerosols.

Nonviable Contaminants from Wastewater: Hexachlorocyclopentadiene Contamination of a Municipal Wastewater Treatment Plant

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ABSTRACT

Municipal wastewater systems have been the repositories of virtually every chemical known to be produced by man. Sewage sludge and wastewaters have been shown to contain numerous toxic contaminants, among them heavy metals, persistent pesticides, and a myriad of other halogenated hydrocarbons. Until recently, there have been few reports of exposure of sewage workers to toxic chemicals. This report describes an episode of acute exposure of sewage workers to the industrial chemical, hexachlorocyclopentadiene. Hexachlorocyclopentadiene is an intermediate compound in the manufacture of pesticides, including aldrin, dieldrin, and Kepone. This episode supports the fact that sewage workers, who are known already to be at increased risk of exposure to infectious agents, must also be considered at risk of exposure to toxic chemicals. As increasing volumes of industrial effluents are channeled each year through municipal wastewater treatment plants, there will be an increasing potential for both acute and chronic exposure of sewage workers to these toxicants. This source of occupational disease deserves continuing evaluation.

More than 1000 new chemical compounds are developed each year in the United States and are related to the approximately 30,000 chemicals and 2 million mixtures, formulations, and blends already in commercial use (1). It appears inevitable that one of the side effects of progress, with its improved standards of living, will be a continued increase in the vast array and complexity of the new chemical compounds entering the wastewater streams. These chemicals for use in domestic, industrial, and business establishments will, through manufacture or use, eventually find their way to the municipal sewerage systems creating a potential for toxic exposures to wastewater treatment plant workers in addition to a more general problem of environmental contamination.

In the past few years there have been significant efforts toward determining the nature and concentrations of chemical contaminants in wastewaters. These efforts have shown that wastewaters contain numerous contaminants, among them heavy metals, chlorinated hydrocarbon pesticides, and a myriad of other organic compounds (2-13). Few studies, however, have characterized the nature of these nonviable contaminants that are emitted into the atmosphere via aerosolization from wastewater treatment facilities, such as trickling filters and the aeration basins of activated sludge processes. A study conducted by Soldano et al. (14) concludes that sewage treatment facilities are a source of airborne organo-mercury compounds, as well as elemental mercury. The aeration basins of activated sludge units are reported to be sources of aerosolized elemental Hg, Pb, and Cd (15), and gaseous NH_3 (16). Carnow et al. (17) conducted a detailed study to determine whether or not an activated sludge plant was posing a health hazard to a Chicago community. Twenty nonviable contaminants were monitored including five gases (NH_3, Cl_2, NO_2, H_2S, and SO_2) and 15 associated with suspended particulate matter (particulate $(SO_4)^=$, $(NO_3)^=$, V, Cr, Mn, Ni, Cu, As, Se, Cd, Sn, Sb, Hg, and Pb). The study concluded that the plant was not having a detectable adverse health effect on residents potentially exposed to the nonviable aerosols emitted. Unfortunately, these studies did not include any consideration of the health effects on sewage workers potentially exposed to these nonviable contaminants. Exposures of sewage workers to H_2S, CH_4, CO_2, and NH_3 produced from the biological degradation of typical domestic waste is well documented (18-21). Much of the information on exposures of sewage workers to organic chemicals of industrial origin has been gathered as a result of accidental or unauthorized discharge of these substances into the sewerage system (22-26). This paper will describe one such episode of acute exposure of sewage workers to the industrial chemical, hexachlorocyclopentadiene (HCCPD) (27). The source of HCCPD was traced to the unauthorized discharge of the compound into a municipal sewer line. HCCPD is extremely toxic by dermal, oral, and inhalation routes of exposure (28). In animals, prolonged intermittent exposure to vapor concentrations at 0.15 ppm led to slight liver and kidney damage. Exposure to higher concentrations caused diffuse degenerative changes of the brain, heart, adrenal glands, liver, and kidneys (29). The long-term effects of a transient exposure are unknown.

BACKGROUND

Sometime during March 1977, an unidentified material began entering the Morris Forman Wastewater Treatment Plant located along the banks of the Ohio River in Louisville, Kentucky. Epidemiologic evidence (Figure 1) suggests that the material may have entered the facility as early as March 14, when there were concurrent above-background-level increases in detection of an objectionable odor and in symptoms (22). The facility operated by the Metropolitan Sewer District (MSD) employs approximately 200 persons and provides primary and secondary treatment for about 97% of the residential and industrial sewage generated by the City of Louisville and Jefferson County. The plant has a capacity of 105 mgd with a peak storm flow capacity of 338 million gallons.

On March 26, four MSD employees, using steam, attempted to remove an odoriferous, highly viscous, and sticky substance from the bar screens and grit collection systems. This attempt produced a blue haze

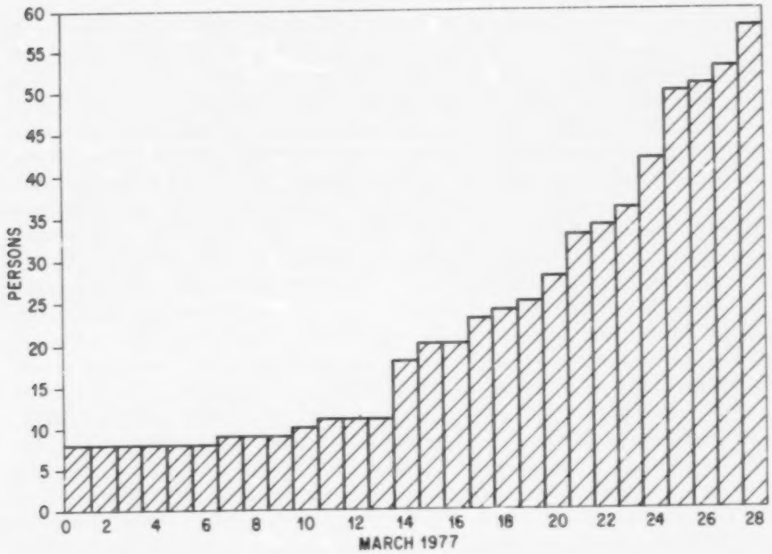

Figure 1. Employees Noticing Unusual Odor at Plant, by Day

which permeated the primary treatment area and caused about 20 workers to seek medical treatment for tracheobronchial irritation. On March 27, following a heavy rain, the operating personnel observed a blue haze hovering over the grit collection channels and an objectionable odor throughout the primary treatment area including the basements of the buildings containing the sludge-pumping equipment. On March 29, the plant was closed when analysis showed the wastewater to be chemically contaminated with HCCPD and octachlorocyclopentene (OCCP). Although airborne concentrations of these chemicals at the time of exposure were unknown, subsequent air monitoring showed the relative airborne concentrations of HCCPD to be much greater than OCCP (27). Four days after the plant closed, HCCPD concentrations in the screen and grit chambers ranged from 270 to 970 ppb. Airborne HCCPD concentrations of the blue haze generated by cleanup procedures measured 19,200 ppb. By comparison, the American Conference of Governmental Industrial Hygienists (1978) recommends an 8-hour time-weighted average threshold limit value of 10 ppb with a short-term 15-minute exposure limit of 30 ppb (30).

Aside from the danger to workers at the plant, other major concerns at the time were for the residents of the area and cities downstream that use the river as a source of water (Figure 2). Air quality monitoring stations, established by the U.S. Environmental Protection Agency (EPA) around the perimeter of the plant and along contaminated sewer lines, indicated that there was no inhalation hazard to the residents of the area. EPA advised that several cities downstream within about 200

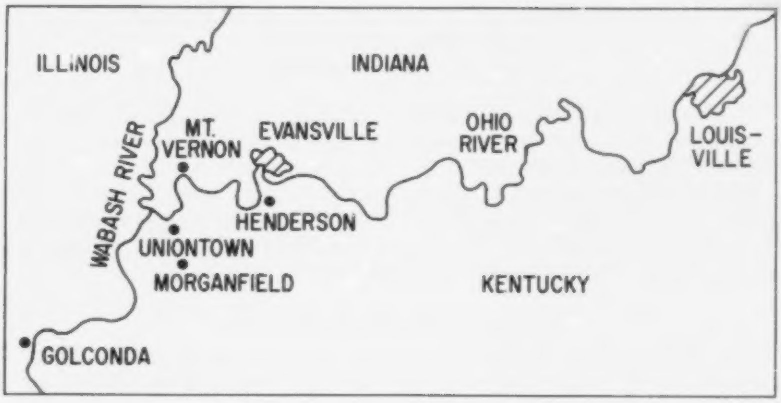

Figure 2. Area Affected by Chemical Wastes

miles, including Henderson, Kentucky; Evansville and Mt. Vernon, Indiana; and Golconda, Illinois, add activated carbon to their maximum capability as a precautionary measure until the potential danger period passed. They also recommended that these cities determine the concentrations of HCCPD and OCCP in the raw and treated finished waters. EPA's involvement has been fully presented by Carter (31).

In the episode reported here, the Hazard Evaluations and Technical Assistance Branch of the National Institute for Occupational Safety and Health (NIOSH) served as the primary agency in safeguarding the health and safety of the workers involved in decontaminating the treatment plant and its contributory sewer lines. Some of the medical and environmental data collected by NIOSH personnel are presented.

MEDICAL ACTIVITIES

The medical activities included questionnaires, physical examinations, blood and urine tests, and review of medical records. A questionnaire was distributed to all employees in May as a follow-up to a similar questionnaire utilized April 1 to 2, 1977, by the Center for Disease Control (22). The NIOSH questionnaire sought information on type and duration of symptoms. The physical examination was directed toward signs of irritation of the skin, mucous membranes, and lungs. Blood specimens were collected and analyzed for complete blood count with differential, serum glutamate oxalacetate transaminase, lactate dehydrogenase, alkaline phosphatase, total bilirubin, albumin, total protein, uric acid, blood urea nitrogen, cholesterol, creatinine, phosphorus, and calcium. Urine specimens were collected for a routine urinalysis. Medical records were reviewed for the 90 employees seen by the plant physician during the period from about March 15 to May 15, 1977.

ENVIRONMENTAL EVALUATION AND HAZARD CONTROL ACTIVITIES

Environmental Monitoring

The workers' airborne exposures to HCCPD and OCCP were concurrently monitored using both personal and work area sampling techniques. The compounds were collected on preextracted Chromosorb 102 (20-40 mesh) packed into 7 cm long 4 mm I.D. glass tubes using vacuum pumps operating at either 0.05 or 0.2 l/min. The analytes were desorbed from the Chromosorb 102 with CS_2 and analyzed using a gas chromatograph equipped with a flame ionization detector (32).

Personal Protective Equipment

The cleanup crew, composed of employees with no or minimal prior exposure to the contaminated sewage, was thoroughly trained in the use and limitations of required personal protective equipment. The type of protective equipment used varied with the conditions of exposure. For example, the workers involved with high-pressure water cleaning of the screen and grit chambers wore full-suit airline respirators consisting of a 0.006-gauge polyvinyl chloride slipover jacket with sealed-on hood and detachable gloves, and trousers with sealed-on boots. Other surface personnel involved with general plant cleanup operations wore either a NIOSH-approved half- or full-face pesticide-removing chemical cartridge respirator. They also wore disposable plastic coveralls or two-piece rubber suits, gloves, rubber boots, or whatever combination of personal protective equipment was necessary to prevent skin contact with the contaminants. Workers involved in decontamination of the main interceptor sewer wore open-circuit self-contained breathing respirators. The breathing air was supplied by an approximately 350 cu ft 2400 psi cylinder attached to each worker's Bobcat® or Caterpillar® tractor. The tractors were used to sequentially push the HCCPD contaminated sewage along the sewer floor to a point for removal by a crane. These workers also wore disposable plastic coveralls taped at the neck and wrists, disposable plastic gloves, and butyl rubber hip boots.

MEDICAL FINDINGS

Questionnaire

Usable responses were received from 177 treatment plant employees (23 females, 154 males). Table 1 shows the type and frequency of symptoms reported immediately prior to plant closure (March 29). Many of these employees still reported symptoms as late as 6 weeks after exposure. Particularly frequent were reports of headache (18%), persistent fatigue (15%), chest discomfort (13%), skin irritation (10%), and cough (9%). The symptoms reported in Table 1 occurred in workers of all job categories and in all work areas. The highest number of symptoms were reported by workers in the primary treatment area and general maintenance personnel.

Medical Examinations

A review of medical records for 90 employees seen by the plant physician from mid-March to May 15 showed similar symptoms of headache

Table 1. Percent of 177 Employees with Symptoms—Questionnaire May 1977

Symptom	Last 2 weeks March	Persistence after onset		
		1 Day	1 Week	May
Eye irritation	62	40	25	9
Headache	55	45	28	18
Chest discomfort	34	30	23	13
Fatigue	34	31	26	15
Sore throat	30	25	11	5
Cough	24	21	14	9
Nausea	22	18	13	6
Skin irritation	21	17	13	10

and mucous membrane and respiratory tract irritation. In addition, several unusual symptoms were reported by persons with a history of acute, high-level exposure including: one report of "burning feet" associated with sludge-related boot deterioration; three reports of "sunburn-like facial irritation;" seven reports of rashes on exposed areas of skin; and seven reports of transient confusion or "memory loss." These last symptoms were not accompanied by other neurological complaints and were not associated with physical signs of neurological impairment. Twenty-eight exposed persons received chest x-rays, none of which showed acute changes. Sixteen of these 28 had arterial blood gas tests, all of which were considered normal. Twenty-two of these 28 persons also had pulmonary function testing with no pattern of abnormality observed.

Because of unexpected changes in MSD personnel during the cleanup operations, NIOSH could not conduct preexposure and serial postexposure monitoring of all 97 cleanup crew members. Consequently, preexposure monitoring was only conducted on 52 (54%) of the 97 total cleanup crew members. Laboratory tests showed no significant abnormalities in renal function tests, complete blood counts, or urinalyses.

Table 2. Abnormalities for 18 of 97 Cleanup Workers

Laboratory Test	Normal Range	Abnormal Results	
		Range	No.[a]
Serum Glutamate Oxalacetate Transaminase	7-40 mU/ml	40-49	5
		50-59	1
		60-69	4
		70-79	0
		80-89	1
		90-99	1
Serum Alkaline Phosphatase	30-100 mU/ml	100-109	3
		110-119	1
		120-129	1
Serum Total Bilirubin	0.15-1.0 mg/%	1.0-1.9	1[b]
Serum Lactate Dehydrogenase	100-225 mU/ml	230-239	1

[a] For individuals with more than one serial blood test, only the most abnormal result is tabulated

[b] Associated with a serum glutamate oxalacetate transaminase result of 66

Several minimal-to-mild abnormalities did appear, however, in liver function studies (Table 2). The abnormalities shown were distributed among 18 (19%) of the 97 cleanup crew members; eight persons had abnormalities on more than one occasion. Seven persons showed a rise in serum glutamate oxalacetate transaminanse that seemed temporally related to exposure to contaminated sewage; all of these persons also had physical signs of mucous membrane irritation.

ENVIRONMENTAL FINDINGS

Table 3 shows the potentially toxic concentrations of HCCPD and OCCP measured during cleanup of the plant's main interceptor sewer. Only one laboratory abnormality (a total bilirubin of 1.4 mg/100 ml serum) was noted among the 12 maximally equipped men involved in this effort, indicating the protective value with respect to acute effects of properly used safety equipment.

Table 3. Air Measurements in Main Interceptor Sewer May 3-28, 1977

			Concentration Data (ppb)		
Chemical	Type of sample	No. of samples	Mean	Median	Range
HCCPD	P[a]	19	1,518	960	21-3,833
HCCPD	WA[b]	41	1,446	1,286	131-4,286
OCCP	P	19	142	91	3- 472
OCCP	WA	41	185	189	17- 416

[a] Sample collected at external surface of worker wearing respirator

[b] Sample collected in work area on other than external surface of worker

DISCUSSION

In this study the wastewater treatment plant workers experienced headache and mucous membrane, skin, and respiratory tract irritation after they were exposed to vapors from sewage contaminated with industrial chemical wastes. Their symptoms were consistent with the known toxic properties of HCCPD, and the distribution of symptoms coincided in time and place with the distribution of HCCPD. Although it was determined that HCCPD was the compound present in the highest airborne concentration, OCCP, a related compound with relatively unknown toxicity, was also present and may have contributed to symptom production.

This episode as well as the Kepone and PCB incidents confirms the fact that sewage workers already known to have increased exposure to infectious agents (33-36) are also at risk of exposure to toxic nonviable contaminants from wastewaters. As increasing volumes of chemically complex industrial effluents are channeled each year through municipal wastewater treatment plants, there will be an increasing potential for both acute and chronic exposure of sewage workers to chemicals having varied toxicologic characteristics. The acute effects from exposure may be readily recognizable, but the effects of long-term, low-level exposure are not known or at best only conjecture. The question of exposure to nonviable contaminants and worker health deserves continuing evaluation.

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DISCUSSION

MR. HAYMES: I am most interested in the prospects for followup.

MR. KOMINSKY: At this time NIOSH does not intend to conduct any medical follow-up on the workers. Prior to leaving the site we outlined to the MSD a plan that should be used for medical monitoring of these workers. We left the follow-up to MSD.

DR. BETTINGER: Regarding your closing conclusion about the potential increasing exposure of workers in municipal treatment plants to these chemicals in the future, the regulations for the Resource Conservation and Recovery Act about to be promulgated, and the manufacturer notification discussion in Section Five of the Toxic Substances Control Act, do you really think that in the future the industrial complex will be allowed to widen groups of materials into treatment plants, as you have suggested, or do you think, perhaps, this may be a diminishing problem?

MR. KOMINSKY: I said accidental or unauthorized discharge. It appears that we are having problems in sewage treatment plants concerning worker health resulting from acute exposures to unauthorized discharges. This is something that regulations cannot control. So I would say that this must be a consideration in the future. But as far as discharge of chemicals by industry on a daily basis in an uncontrolled fashion, I would say it will not increase.

DR. WARD: What happened to the sewage during the time that the plants were broken down? Did it go in the river?

MR. KOMINSKY: Correct. During the period of closure approximately 1 mgd of raw sewage was directed to the river. Fortunately, because of the solubility characteristics of hexa, much hexa was not leaving the contaminated sewer lines. But obviously EPA was monitoring the river.

DR. WARD: I realize that not much can be done about this, nor is it your job to do it when something like this happens. However it points out some of the different risks that we are looking at, where, normally, you are down to zero levels or close to that and then suddenly you are up to levels that wipe out the advantages of anything you might have done for the last 25 years.

MR. KOMINSKY: That is very true.

A Model for Predicting Dispersion of Microorganisms in Wastewater Aerosols

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ABSTRACT

A dispersion model framework for predicting the viable airborne concentrations of specific microorganisms dispersing from a nearby source of wastewater aerosols is presented. Estimates and estimation procedures for key model parameters such as the viability decay rate were developed from field monitoring data. In the specific model applicable to spray irrigation, model parameters representing aerosolization efficiency and the initial aerosol impact effect on microorganisms were also evaluated. The procedure for predicting downwind microorganism levels is illustrated using several examples.

Model validation using indicator organisms at two other spray irrigation sites implies the model predictions have order-of-magnitude accuracy and precision within several hundred meters of the source. The applicability of the model to estimating the dose of microorganisms inhaled by humans in the vicinity of a wastewater aerosol source is considered.

Background

The study of man-made air pollution and chemical and biological warfare defenses has fostered the development in the last quarter century of sophisticated mathematical models for describing the atmospheric diffusion of inert gases and small particle aerosols (<20 µm in diameter). These models are generally a cost-effective replacement of direct field monitoring as a means of estimating pollutant aerosol concentrations downwind from point sources. They also permit assessments of the effects of new sources and of the effectiveness of possible control strategies on existing sources. In these models, the pollutant concentration in air at a distance downwind and along the centerline from a constantly emitting pollutant source may be represented in the general form

$$C_d = Q \bullet D_d + B \qquad \text{(Equation 1)}$$

as described in Figure 1.

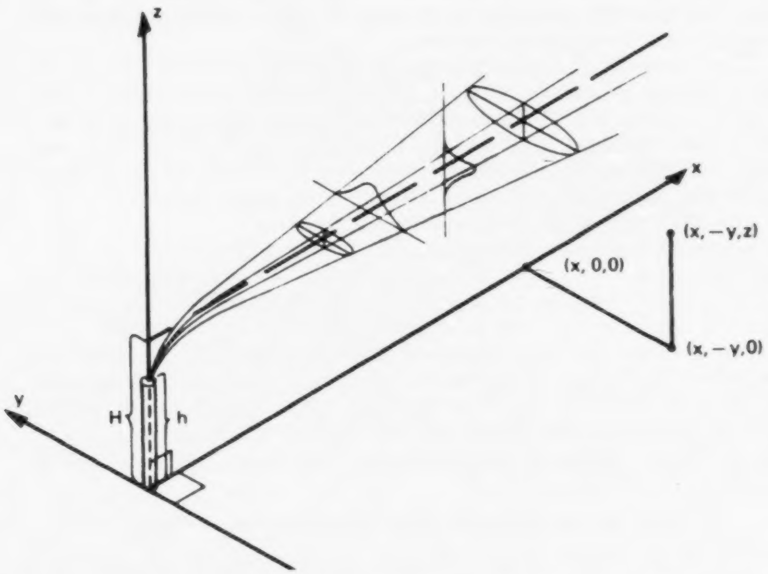
For estimating short-term (averaging time <30 minutes) pollutant concentrations downwind of the source, the diffusion factor D_d is generally expressed in the Gaussian form depicted in Figure 2. The Gaussian model assumes that diffusion of pollutant from the point source during its transport downwind leads to a Gaussian (i.e., normal) distribution of the pollutant concentration in both the crosswind (y) and vertical (z) directions about the downwind centerline (x-axis). Gaussian models have been derived, parameterized, and popularized by Cramer (1-3),

$$C_d = P_d + B$$

where $P_d = Q \cdot D_d$

and d = downwind distance (m)
C_d = pollutant air concentration at d (mass/m³)
P_d = model prediction of pollutant air concentration coming from the source (mass/m³)
B = background air concentration of pollutant (mass/m³)
Q = source strength (i.e., pollutant emission rate) (mass/sec)
D_d = diffusion factor at d (sec/m³)

Figure 1. General Form of Atmospheric Diffusion Models



$$D_d(y,z) = \frac{1}{2\pi u \sigma_y \sigma_z} e^{-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2} \left[e^{-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2} + e^{-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2} \right]$$

where x = distance in downwind direction, (m)
y = distance in cross-wind direction, (m)
z = distance in vertical direction, (m)
u = mean wind speed, (m/sec)
σ_y = standard deviation of plume concentration distribution in the crosswind direction, (m)
σ_z = standard deviation of plume concentration distribution in the vertical direction, (m)
H = height of plume center-line, (m)

Figure 2. Gaussian Form of the Diffusion Factor D_d

Hay (4,5), Pasquill (6), Gifford (7), and Turner (8), among others (9). Appropriate adjustments can be made to the basic model to account for various phenomena when their effects become significant (8,10,11). Such phenomena include plume rise, gravitational settling as a function of particle size, pollutant decay with time, reflection and/or deposition at horizontal mixing boundaries (such as the ground or a temperature inversion), and precipitation scavenging (i.e., wash-out). Gaussian models have been validated (12,13), are recommended (14), and are currently in wide use.

At downwind distances that have the same order of magnitude as the dimensions of the aerosol source, the pollutant concentration pattern due to atmospheric diffusion depends strongly on the configuration of the aerosol source. Typical normalized isopleths of the diffusion factor D_d of the Gaussian model are presented in Figure 3 for point, line, and area sources of wastewater aerosols.

The dispersion of microorganisms in wastewater aerosols can also be predicted using Gaussian models, provided factors are included to take into account the die-off characteristics of the microorganisms. A biological exponential decay factor $e^{\lambda a_d}$ is usually proposed (15,16) to account for microorganism inactivation with increasing aerosol age due to environmental stress (e.g., solar irradiation or dessication), where

$a_d = d/u$ = aerosol age (sec) at distance d, and

λ = viability decay rate of the microorganism, (sec^{-1}) ($\lambda<0$)

Viability decay rates have been estimated for various microorganisms under various conditions in controlled chamber tests (17,18). An additional die-off effect I occurring immediately upon aerosolization of the microorganisms has been observed (19). Its magnitude has been estimated for the standard plate count of total viable bacterial particles from a field study at a spray irrigation site (20). By incorporating these factors into the Gaussian model to account for the observed die-off characteristics of relevant groups of microorganisms, one obtains the microbiological dispersion model.

THE MICROBIOLOGICAL DISPERSION MODEL

The microbiological dispersion model was originally developed (21) as a model for microorganism dispersal in the wastewater aerosols produced when wastewater is applied to land by spray irrigation.* The notation for representing the factors comprising the model has since been revised (22) and generalized (23) for application to other sources of wastewater aerosols.

General Form of Model

The general form of the microbiological dispersion model may be represented as

$$C_d = Q \cdot D_d e^{\lambda a_d} + B \qquad \text{(Equation 2)}$$

This general form can be used to predict microorganism concentrations in the vicinity of sources which have aerosol formation processes too

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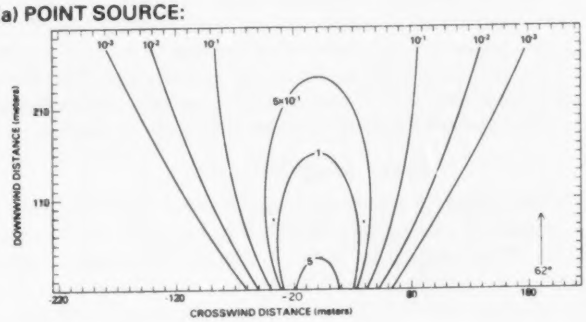
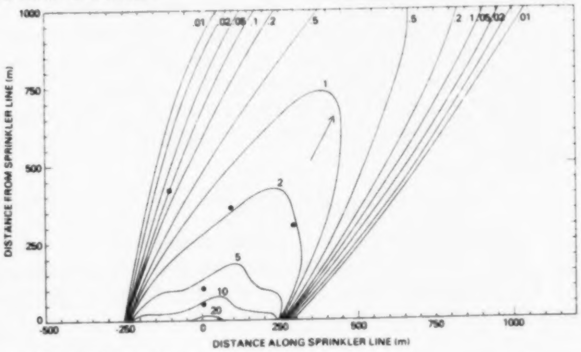
*It is U.S. EPA policy to promote use of land treatment processes to reclaim and recycle municipal wastewater. Slow rate application of wastewater to land by spray irrigation (also termed sprinkler irrigation) is perhaps the most popular application method.

(a) POINT SOURCE:



(b) LINE SOURCE:



(c) AREA SOURCE:

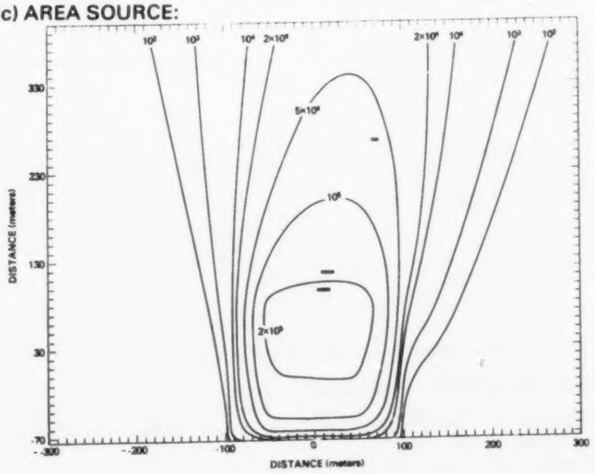


Figure 3. Diffusion Patterns D_d for Various Source Configurations

complex to postulate an estimable mathematical model for the source strength Q. Various sewage treatment units, including aeration basins, trickling filters and aerated surge basins, and cooling towers utilizing wastewater are examples of wastewater aerosol sources for which the general forms given by Equation 2 may be appropriate. For the general form of the model, the source strength Q is usually estimated by field sampling the wastewater aerosol just downwind of the source.

Spray Irrigation Form

For some processes of generating wastewater aerosols, the components of a model of the aerosol-generating process can be estimated separately. A more detailed form of the microbiological dispersion model in which a suitable aerosol formation model replaces Q is then preferable. Land application of wastewater by spray irrigation is one such process.

The spray irrigation form of the microbiological dispersion model is presented in Figure 4. Here the source strength Q is represented as the product W•F•E•I of the wastewater concentration (W), the flow rate (F) of wastewater being sprayed, the aerosolization efficiency (E), and the initial microorganism impact (I). Substitution for Q in Equation 2 yields a microbiological dispersion model for wastewater aerosols generated by spray irrigation:

$$C_d = W \bullet F \bullet E \bullet I \bullet D_d \bullet e^{\lambda a_d} + B \qquad \text{(Equation 3)}$$

With suitable estimates of the model parameters (W, F, E, I, D_d, λ and B), Equation 3 can be used to predict microorganism concentrations in the vicinity of a spray irrigation site, with little or no requirement for field sampling the wastewater aerosol at the site.

(a) *GENERAL FORM:*

$$C_d = P_d + B$$

where $P_d = Q \bullet D_d \bullet e^{\lambda a_d}$

(b) *SPRAY IRRIGATION FORM:*

$$C_d = P_d + B$$

where $P_d = W \bullet F \bullet E \bullet I \bullet D_d \bullet e^{\lambda a_d}$

Q = W•F•E•I

W = microorganism concentration in the wastewater (cfu/L)

F = flow rate of wastewater being sprayed (L/sec)

E = aerosolization efficiency factor (i.e., the fraction of sprayed wastewater that becomes aerosol) $(O < E < 1)$

I = microorganism impact factor (i.e., the aggregate effect of all microorganism-specific factors affecting measurement and survival during the aerosol formation process $(I > 0)$

Figure 4. The Microbiological Dispersion Model

ESTIMATING THE PARAMETERS E, I, λ, B, AND Q

The usefulness of the microbiological dispersion model is enhanced because the values of the model parameters E, I, and λ appear to be relatively independent of the site at which the wastewater aerosol was generated. The estimates of E, I, λ, and B given in this section were derived from five field sampling studies. The primary field study (22,24) involving 77 aerosol runs was conducted by Southwest Research Institute at a sprinkler irrigation site in Pleasanton, California, that sprayed 1.4 mgd (5.3×10^6 l/day) of unchlorinated secondarily-treated wastewater. Additional data were obtained from smaller field sampling studies of two activated-sludge aeration basins [Egan Plant, Schaumburg, Illinois (25,26) and Durham Plant, Tigard, Oregon (27,23)] and of two other sprinkler irrigation systems [Fort Huachuca, Arizona (20,28) and Deer Creek Lake State Park, Ohio (29)].

Aerosolization Efficiency E

In the spray irrigation studies, dye aerosol samples were collected downwind after injecting a fluorescent dye into the wastewater. The aerosolization efficiency E was determined as the ratio of the dye aerosol concentration sampled downwind to the diffusion model prediction at that location calculated assuming all of the dyed wastewater had been aerosolized. The estimates obtained for the proportion of wastewater that was aerosolized during the spray irrigation are presented in Table 1. The median estimate at each of the three sites was about 0.003 (i.e., 0.3% of the sprayed wastewater evaporated before reaching the ground). However, the estimates from individual dye runs varied by over an order of magnitude, depending upon meteorological conditions which affect the evaporative capability of the air. The regression equation shown in Figure 5 was developed from the Pleasanton data. Eighty percent of the variation in aerosolization efficiency at Pleasanton can be explained by this equation in which log E increases substantially with the ambient temperature and slightly with the product of wind velocity and solar radiation. This equation appears adequate to predict E for spray sites using rotating impact sprinklers.* With a revised constant based on several dye runs, modified equations could be developed for other types of sprinkler equipment.

Table 1. Estimates of Aerosolization Efficiency E

Site of spray irrigation	No. of dye runs	Distribution of E values (percentiles) 10%	25%	50% (median)	75%	90%
Pleasanton, CA	17	0.09%	0.19%	0.33%	0.64%	1.8%
Fort Huachuca, AZ	3			0.29%		
Deer Creek Lake, OH	4			0.47%		

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*Rotating sprinklers with Rainbird® impact nozzles were used at all three spray irrigation sites.

$$\mathrm{Log}_{10}E = 0.031\,t + 0.000096\,u \cdot r - 3.10$$

where
t = air temperature, °C
u = wind speed, m/sec
r = solar radiation, W/m²

$R^2 = 0.80$

Figure 5. Prediction Equation for E at Pleasanton

Microorganism Impact I

The pattern of die-off of a microorganism with distance during an aerosol run, after accounting for aerosolization efficiency, was used to estimate the microorganism impact I and the viability decay rate λ of the microorganism during the run. I and λ were estimated from the intercept and slope parameters, respectively, of the simple linear regression of the log concentration pattern $\ln\left(\frac{C_d - B}{W \cdot F \cdot E \cdot D_d}\right)$ on aerosol age (22).

The distributions of the impact estimates obtained for each microorganism from the Pleasanton data are presented in Table 2. Preliminary analysis (22) suggested reduced initial survival (i.e., low I values) may be associated with low relative humidity, high wind velocity, and a large temperature difference between the wastewater and the air, but no definite relationship has yet been established. From the differences in their I value distributions, it is apparent that microorganisms vary markedly in their ability to survive the initial shock of aerosolization.

Table 2. Estimates of Microorganism Impact I at Pleasanton

	No. of aerosol runs	Distribution of I values (percentiles)						
		10%	25%	40%	50% (median)	60%	75%	90%
Fecal coliforms	13		0.068		0.13		0.58	
Total coliforms	44	0.016	0.060	0.13	0.16	0.23	0.55	1.1
Standard plate count	33	0.036	0.11	0.19	0.21	0.24	0.35	1.2
Coliphage	43	0.017	0.094	0.18	0.34	0.52	0.91	1.8
Mycobacteria	8		0.77		0.89		2.1	
Clostridium perfringens	11		0.24		1.2		6.5	
Fecal streptococci	31	0.27	0.71	0.97	1.7	2.7	6.1	32
Pseudomonas	13		1.7		14		73	
Enteroviruses	2				40[a]			

[a] Approximate value

Viability Decay Rate λ

Table 3 gives the distributions of viability decay rates for each microorganism derived from the Pleasanton data. Frequently, microorganism die-off with aerosol age could not be detected ($\lambda = 0$) at Pleasanton, especially for such hardy microorganisms as fecal streptococci, *Pseudomonas*, and mycobacteria. Preliminary analysis (22) implied viability decay may be more rapid with high solar radiation, high temperatures, and middle-to-low relative humidities, but no definite relationship has been established.

The distribution of viability decay rates for the Pleasanton spray irrigation system were compared (23) to the limited distributions obtained from sampling the Durham aeration basin (Table 4). At the 0.10 significance level, no significant λ differences were found between sites for any microorganism by the two-sample Kolmogrov-Smirnov test (30) of distributional differences or by the signed ranks test (31) of shifts in location. The inability to detect a significant difference may be due to the variability in λ and limited number of λ estimates (six per microorganism) available for the Durham site.

Table 3. Estimates of Viability Decay Rate λ at Pleasanton

	No. of aerosol runs	Distribution of λ (sec $^{-1}$) values (percentiles)						
		10%	25%	40%	50% (median)	60%	75%	90%
Total coliforms	44	−0.23	−0.094	−0.050	−0.032	−0.020	−0.004	[a]
Fecal coliforms	13	−0.19	−0.070		−0.023		[a]	
Coliphage	43	−0.11	−0.051	−0.029	−0.011	[a]	[a]	[a]
Clostridium perfringens	11	−0.10	−0.039		−0.004[b]		[a]	[a]
Standard plate count	33	−0.12	−0.020	−0.006	−0.004[b]	[a]	[a]	
Mycobacteria	8	−0.15[c]	−0.009[b]		[a]		[a]	
Pseudomonas	13	−0.08	−0.008[b]		[a]		[a]	
Fecal streptococci	31	−0.06	−0.008[b]	[a]	[a]	[a]	[a]	[a]

[a] Indeterminate viability decay rate; for model calculations, [a] may be presumed to represent the value 0.0
[b] Questionable value, perhaps indistinguishable from zero
[c] Approximate value (extrapolated)

Background Concentration B

The standard procedure for estimating the background air concentration of a microorganism in a wastewater aerosol monitoring study is to take samples upwind of the aerosol source simultaneously with samples taken downwind during an aerosol run. B may then be computed as the geometric mean of the upwind concentration values over all the aerosol runs performed. Using this approach, background concentrations of prevalent and relevant microorganisms were computed from the various field monitoring studies and are presented in Table 5. There is considerable variation in the background concentration from site to site as shown by the geometric means in Table 5. However, there also is substantial variation in the measured upwind concentration from one run to another at the same site. Ambient background concentrations of potentially pathogenic microorganisms are difficult to establish accurately because they are usually below the lower detection limit of any sampling-assay protocol available for the aerosol monitoring effort.

Table 4. Comparison of Viability Decay Rates at Two Sites

	Viability decay rate λ (sec. $^{-1}$) —25th percentile		
	Pleasanton spray irrigation	Durham, OR Sewage Treatment Plant (6 aerosol runs)	Significant difference?
Total coliforms	−0.094	−0.06	No
Coliphage	−0.051	−0.05	No
Mycobacteria	−0.009	−0.06	No
Fecal streptococci	−0.008	−0.05	No

Table 5. Background Concentrations B at Various Sites

	Geometric mean background concentration[a] (cfu/m³)				
	Spray Irrigation sites			Sewage Treatment Plants	
	Pleasanton	Ft. Huachuca	Deer Creek	Egan, Chicago	Durham, OR
Standard plate count	460	41	89	2,100	—
Total coliforms	0.1	1.3	—	0.6	<0.01
Fecal coliforms	0.02	—	—	0.1	—
Coliphage (pfu)	0.01	—	—	0.01	<0.02
Fecal streptococci	0.2	—	—	<1	0.03
Mycobacteria	0.2	—	—	—	<0.01
Pseudomonas	3	—	—	<2	<2

[a] "Background" measurements taken at upwind locations during aerosol runs

Source Strength Q

Practical difficulties usually make it impossible to estimate the source strength Q in the general form of the microbiological dispersion model by field sampling the microorganism concentration C_o of the wastewater aerosol right at its source. In these situations, Q and λ can be estimated by field sampling the wastewater aerosol simultaneously at two distances d_1 and d_2 downwind of the source. The two downwind sampling distances should be sufficiently close to the source that the sampled microorganism air concentrations C_1 and C_2 both clearly exceed the background concentration B. However d_1 and d_2 must also be sufficiently separated that their aerosol ages a_1 and a_2 are substantially different. When these conditions are met, a point estimate of the viability decay rate $\hat{\lambda}$ for the field sampling run can be obtained by evaluating Equation 2 at the two sampled distances:

$$\hat{\lambda} = \frac{\ln[(C_1 - B)/D_1] - \ln[(C_2 - B)/D_2]}{a_1 - a_2} \qquad \text{(Equation 4)}$$

The $\hat{\lambda}$ point estimate determined from Equation 4 may disguise considerable uncertainty in the estimate, particularly if $a_1 - a_2$ is small, if C_1 or C_2 are not appreciably greater than B, or if the uncertainties in $(C_1-B)/D_1$ or $(C_2-B)/D_2$ are relatively large. The $\hat{\lambda}$ estimate from Equation 4 should be compared to the microorganism's λ distribution given in Table 3 to determine whether the $\hat{\lambda}$ point estimate appears realistic. Because of the uncertainty in its value, the $\hat{\lambda}$ estimate from equation 4 will often be inadequate for predicting microorganism aerosol concentrations at downwind distances much greater than the sampled distances.

The source strength Q and the air concentration C_o of microorganisms at the source that survived aerosolization can be estimated for this sampling run using the $\hat{\lambda}$ estimate:

$$\hat{Q} = \left(\frac{C_1 - B}{D_1}\right) e^{-\hat{\lambda} a_1} \qquad \text{(Equation 5)}$$

$$\hat{C}_o = B + \hat{Q} D_o \qquad \text{(Equation 6)}$$

The accuracy of the source air concentration estimate may suffer because complex source geometry and source turbulence often make it difficult to accurately estimate the diffusion factor at the source (i.e., D_o) and at small downwind distances.

CONCENTRATION PREDICTIONS USING THE MODEL

Spray Irrigation Model

Calculation Procedure

The following steps comprise the procedure for applying the spray irrigation form of the microbiological dispersion model (Equation 3) to predict aerosol concentrations in the vicinity of a spray irrigation site:

1. Choose the centerline downwind distance and weather conditions to be evaluated. Calculate the aerosol age a_d at distance d.
2. Select a relevant microorganism and measure its typical concentration W in the wastewater before it becomes aerosolized. W should be determined as the geometric mean of assays for the microorganism from several samples of the wastewater.
3. Determine the total flow rate F of wastewater being applied to land through the spray irrigation system; F is usually measured at the pump.
4. Estimate the background concentration B of the microorganism in the air.
5. Apply a suitable air pollutant dispersion model to calculate D_d based on such site-specific information as the configuration of the aerosol source(s), weather conditions, local topography, and distance to the downwind location.
6. Select an aerosolization efficiency value E appropriate for the type of spray system, operating spray pressure, and weather conditions, perhaps by using the equation in Figure 5.
7. Select appropriate values of I and λ for the microorganism, considering the weather conditions. In the absence of established weather relations, percentiles in Tables 2 and 3 ranging from the 25th percentile to the 75th percentile may be chosen: the 25th percentile for very adverse conditions (high solar radiation, perhaps), the 50th percentile for typical conditions, and the 75th percentile for very favorable conditions (warm, humid nights, perhaps).
8. Calculate the predicted centerline air concentration P_d at distance d produced by the aerosol source(s) and the downwind air concentration C_d by using Equation 3.

Prediction Example—Pleasanton Residential Area

As an example of the calculation procedure, the spray irrigation model was used to make rough estimates of the aerosol concentrations of total coliforms, mycobacteria, and human enteroviruses to which the nearest residents to the spray fields in Pleasanton, California were typically exposed during summer. These residents lived in a subdivision, the closest edge of which was located about 650 east and southeast of the edge of the spray fields.

Two cases were considered: 1) nighttime (perhaps corresponding to maximal exposed concentration when downwind); and 2) midday (perhaps corresponding to the minimal exposed concentration when downwind). The meteorological conditions and site layout used as model inputs for both cases are presented in Table 6. Sample computations for total coliforms and enteroviruses at night are provided in Table 7 showing the model parameter values obtained using the preceding calculation

Table 6. Meterological Conditions and Site Layout for Spray Irrigation Prediction Examples

Meteorological Conditions	Summer night	Summer midday
Air temperature, t	20°C	30°C
Relative humidity	70%	40%
Solar radiation, r	0 W/m^2	1,000 W/m^2
Wind velocity, u	2 m/sec	4 m/sec
Stability class	E	B
Mixing height	30 m	High
Site Layout	**Pleasanton, CA**	**Deer Creek Lake, OH**
Sprinkler type	Rainbird® impact	Rainbird® impact
Sprinkler configuration	Line-Fig. 3(b)	Rectangular grid-Fig. 3(c)
Number of sprinklers	52	96
Inhabited area	Subdivision	Campsite
Direction of sprinklers	E and SE	NE
Distance from edge of sprinklers, d	650 m	700 m
Aerosol age, a (summer night)	325 sec	350 sec
Aerosol age, a (summer midday)	162.5 sec	175 sec

procedure. In the absence of predictive relationships for I and λ, the 60th percentile of the I and λ distributions was chosen as appropriate for the nighttime case; the 40th percentile was selected for the midday case. With aerosol ages as large as in these examples, the exponential decay term $e^{\lambda a_d}$ based on an uncertain λ value often predominates the calculation. Hence, the predicted concentration P_d may disguise substantial uncertainty as to its proper value.

In Table 8, the resulting model predictions of the centerline concentration are compared to the background concentrations B measured at Pleasanton. For total coliforms and mycobacteria, the model-predicted concentrations entering the residential area are less than the measured background concentrations, even during the nighttime case. The model

Table 7. Examples of the Spray Irrigation Model Calculation Procedure: Approximate Concentrations in Inhabited Area When Downwind on a Summer Night

Site/inhabited area:	Pleasanton, CA subdivision		Deer Creek Lake, OH campsite
Microorganism group:	Total coliforms	Enteroviruses	Total coliforms
Model parameters			
W	10,000,000 cfu/l	50 pfu/l	180,000 cfu/l
F	70 l/sec	70 l/sec	30 l/sec
E	0.0033	0.0033	0.0047
I^a	0.23	60^b	0.23
D_d	0.000017 sec/m^3	0.000017 sec/m^3	0.00002 sec/m^3
λ^a	−0.02 sec^{-1}	$-0.002^{b,c}$ sec^{-1}	−0.02 sec^{-1}
$P_d = W \cdot F \cdot E \cdot I \cdot D_d \cdot e^{\lambda a_d}$	0.01 cfu/m^3	0.006 pfu/m^3	0.0001 cfu/m^3
B	0.1 cfu/m^3	$0.^c$pfu/m^3	0.1^c cfu/m^3
$C_d = P_d + B$	0.1 cfu/m^3	0.006 pfu/m^3	0.1^ccfu/m^3

[a] 60th percentile selected for these meteorological conditions
[b] Extrapolated value
[c] Little basis for a numerical estimate

Table 8. Summary of Approximate Predicted Centerline and Background Concentrations in Spray Irrigation Examples

	P_d		B
	Summer night	Summer midday	Background
Pleasanton, CA Subdivision			
Total coliforms (cfu/m³)	0.01	0.001	0.1
Mycobacteria (cfu/m³)	0.09	0.06	0.2
Enteroviruses (pfu/m³)	0.006	0.002	—
Deer Creek Lake, OH campsite			
Total coliforms (cfu/m³)	0.0001	7×10^{-6}	0.1[a]
Fecal streptococci (cfu/m³)	0.005	0.0009	0.2[a]

[a] Little basis for a numerical estimate

predictions suggest that, at these residential distances, the downwind air concentrations of hardy but relatively rare wastewater microorganisms such as the enteroviruses may equal or exceed those of prevalent wastewater indicator microorganisms such as total and fecal coliforms.

Prediction Example—Deer Creek Lake Campsite

As another example, rough estimates were also made of the microorganism levels to which campers are exposed in the summer at a campsite located a minimum of 700 m northeast of a wastewater spray irrigation site at Deer Creek Lake, Ohio. Both a nighttime and a midday case were considered using the meteorological conditions and site layout listed in Table 6 as model inputs. A sample computation for total coliforms at night is presented in Table 7. The approximate centerline concentrations of total coliforms and fecal streptococci predicted to be entering the campsite when it is downwind of the spray field are summarized in Table 8. Because the aerosol ages are relatively large, the computed value of P_d may hide the considerable uncertainty as to its actual value. Notice that the predicted exposure concentrations from the wastewater spray source are considerably less than the presumed background concentrations surmised from the field monitoring at Pleasanton (Table 5).

General Form of Model Supplemented by Field Sampling

Calculation Procedure (Two Downwind Sampler Distances)

The distribution of microorganism concentrations near any wastewater aerosol source can be predicted using the following procedure. A limited field sampling program is necessary. It should consist of several sampling runs involving simultaneous air samples taken upwind and at two (preferably three or more) separated downwind distances. Each sampling run provides an estimate of λ, Q, and a downwind concentration prediction P_d. However, P_d depends largely on λ for downwind distances larger than the sampled distances, and the estimate of λ may be very imprecise. Thus, this procedure is *not* recommended for predicting the distribution of P_d at large downwind distances. The procedure is as follows:

1. Choose the centerline downwind distance d, the relevant microorganism(s), and the general weather conditions to be evaluated.
2. Conduct several field sampling runs for the relevant microorganism(s) under the chosen weather conditions. During each sampling run, the microorganisms' air concentrations should be simultaneously monitored upwind and at two (or more) separated but relatively short downwind distances d_1 and d_2 from the wastewater aerosol source.
3. Estimate the background concentration B for each microorganism during each run from the upwind samples.
4. Determine the measured downwind concentrations C_1 and C_2 of each microorganism and the aerosol ages a_1 and a_2 at the downwind sampler distances.
5. Apply an appropriate air pollutant dispersion model to calculate D_1, D_2, and D_d, based on such site-specific information as the configuration of the aerosol source, the weather conditions, local topography, the downwind sampler distances d_1 and d_2, and the downwind distance d of the prediction.
6. Compare the microorganism viability decay rate λ during the sampling run as computed from Equation 4 with the λ distribution of the microorganism shown in Table 3. Select an appropriate estimate for λ based on the available information.
7. Estimate the source strength Q during the sampling run from Equation 5.
8. Calculate the predicted air concentration P_d emanating from the aerosol source to the centerline distance d during the sampling run, and the total air concentration there (C_d) using Equation 2.

Prediction Example—Durham Elementary School

To illustrate the calculation procedure for the general form of the microbiological dispersion model, an example is given for an aeration basin. The model was used to make very rough estimates of the aerosol concentrations of mycobacteria and other bacteria to which children may have been exposed while attending an elementary school located about 450 m northeast of the aeration basin of the Durham Wastewater Treatment Plant, Tigard, Oregon. When the school was downwind of the aeration basin, the days were cool and often rainy. Table 9 displays the calculation procedure for predicting the mycobacteria aerosol concentration at 450 m downwind during one field sampling run performed under cool humid conditions. The distribution from the six aerosol runs of predicted aerosol concentrations of total coliforms, mycobacteria, and fecal streptococci at the distance of the school downwind is contrasted with the background concentration in Table 10. There is broad variation in the predicted concentrations of each microorganism at the school distance. For relatively large aerosol ages the exponential factor $e^{\lambda a_d}$ predominates the P_d calculation. Consequently, the considerable uncertainties in the point estimates $\hat{\lambda}$ from Equation 4 are magnified in the calculation of P_d for sizable downwind distances.

Table 9. Example of Calculation Procedure for General Form of Model Supplemented by Field Sampling

Site layout	
Wastewater Aerosol Source	Aeration Basin
Inhabited Area	Elementary School
Direction from Source	NE
Distance from Source, d	450 m
General Weather Conditions	Cool Days, Often Rainy
Relevant Microorganism	Mycobacteria
Field Sampling Run	
Date	3-9-78
Time	1040–1110
Air Temperature	10°C
Relative Humidity	65%
Cloud Cover in Eighths	5
Solar Radiation	98 W/m^2
Mean Wind Speed, u	2.1 m/sec
Mean Wind Direction	15°
Wind Direction Range	310° to 50°
Background Air Concentration, B	<0.01 cfu/m^3

Locations:	Sampler 1	Sampler 2	Prediction
Distances, d	$d_1 = 37$ m	$d_2 = 82$ m	$d = 450$ m
Aerosol Ages, a	$a_1 = 18$ sec	$a_2 = 39$ sec	$a_d = 214$ sec
Diffusion Factors, D	$D_1 = 0.0073$ sec/m^3	$D_2 = 0.0025$ sec/m^3	$D_d = 0.00024$ sec/m^3
Sampled Air Concentrations, C	$C_1 = 9.3$ cfu/m^3	$C_2 = 1.3$ cfu/m^3	
Viability Decay Rate, $\hat{\lambda}$ (eq. 4)		-0.040 sec^{-1}	
Source Strength, $\hat{Q}$ (eq. 5)		610 cfu/sec	
$P_d = \hat{Q} \cdot D_d e^{\hat{\lambda} a_d}$			0.00003 cfu/m^3
$C_d = P_d + B$			<0.01 cfu/m^3

VALIDITY OF SPRAY IRRIGATION MODEL PREDICTIONS NEAR THE SOURCE

The predictive value of the spray irrigation model has been investigated through a validation study (22) in which model-predicted aerosol concentrations were compared against field-sampled downwind aerosol concentrations corrected for the background concentration.

Validation Procedure

Sampled aerosol data were taken from the field studies at Deer Creek Lake and Fort Huachuca and from the Pleasanton runs not used in developing the model. Predictions were made for each sampler distance

Table 10. Distribution of Model Predictions at School Distance from Durham Aeration Basin

	P_{450}			B
	25%	50%	75%	Background
Total coliforms (cfu/m^3)	5×10^{-7}	5×10^{-5}	0.002	<0.01
Mycobacteria (cfu/m^3)	2×10^{-6}	4×10^{-5}	0.2	<0.01
Fecal streptococci (cfu/m^3)	2×10^{-6}	3×10^{-4}	0.03	0.03

Table 11. Validation Data for Spray Irrigation Model

	Number of pairs of predicted (P_d) and measured (C_d-B) values			
	Pleasanton	Ft. Huachuca	Deer Creek	Total
Standard plate count	6	45	34	85
Total coliforms	8	24	0	32
Fecal coliforms	5	1	0	6
Coliphage	5	15 (seeded)	0	20
Fecal streptococci	8	0	0	8

during each run using the calculation procedure described above for the spray irrigation model. The amount of validation data is shown in Table 11. Enough field data were available to thoroughly test the model predictions for the standard plate count within 200 m of the wastewater spray source, when a variety of sampling and analytical procedures were used. Useful evaluations were obtained for total coliforms and coliphage nearer the source. However, the predictive ability of the model for potentially pathogenic microorganisms remains untested at sites other than Pleasanton.

Because most of the field data utilized were obtained within 50 m of the spray source, this model validation emphasizes the adequacy of the model parameters E and I rather than λ. Since the estimates of λ vary widely, both the accuracy and precision of the model predictions are likely to deteriorate with distance from the spray source.

Accuracy

The ratio of the predicted to the measured concentration, $P_d/(C_d\text{-}B)$, was used to evaluate prediction accuracy. Predictions of the model were quite accurate when the sprayed wastewater did not contain residual chlorine, as Table 12 indicates. The predictions P_d for most microorganisms tended to be slightly smaller than the net measured aerosol concentrations (C_d-B), averaging 64% of the net measured value for standard plate count and 73% for total coliforms and coliphage. The total coliform and coliphage predictions exhibited no significant bias. While the prediction underestimates for standard plate count, and fecal coliforms are statistically detectable, their small magnitude (i.e., about a factor of

Table 12. Accuracy of Spray Irrigation Model Predictions Near the Source

	Predicted/measured geometric mean	Assessment of prediction bias
Total coliforms	0.73	Unbiased
Coliphage	0.73	Unbiased
Standard plate count	0.64	Slight underprediction
Fecal coliforms	0.40	Slight underprediction
Fecal streptococci	4.2	Unknown

Table 13. Spray Irrigation Model Underprediction of Standard Plate Count for Chlorinated Wastewater Aerosols

	Total residual chlorine	Predicted/measured geometric mean
High chlorination	6 ppm	0.006[a]
Low chlorination	0.2 ppm	0.55
Unchlorinated	<0.1 ppm	0.76

[a] Approximate value

2) is insignificant in most model applications. As Table 13 illustrates, model predictions substantially underestimated the net measured aerosol concentrations of the standard plate count when the sprayed wastewater contained high levels of residual chlorine.

Table 14. Precision of Spray Irrigation Model Predictions Near the Source

	Discrepancy between predicted and measured values	
	Factor geometric mean	Percentage below a factor of 5
Standard plate count	2.7	77
Coliphage	2.9	80
Total coliforms	4.4	71
Fecal coliforms	4.9	71
Fecal streptococci	4.9	60

Precision

The discrepancy factor, defined as the larger of $(C_d\text{-}B)/P_d$ and $P_d/(C_d\text{-}B)$, was used to investigate the precision of the model predictions. The results are summarized in Table 14. Most of the model predictions made (e.g., 77% of standard plate count predictions, 71% of total coliform predictions, and 80% of the coliphage predictions) were within a factor of 5 of the net measured value. The average discrepancy was less than a factor of 3 for standard plate count and coliphage, and less than a factor of 5 for total coliforms, fecal coliforms, and fecal streptococci.

DISCUSSION

The process by which the microorganisms in wastewater are aerosolized and transported downwind to a receptor location is complex and involves many variables. Any mathematical model of this process that is used to predict the density of microorganisms in the air at the receptor must make many simplifying assumptions. Furthermore, the numerical simplicity of the calculation may encourage the extrapolation to receptor distances at which the model predictions are meaningless and may thus be misleading. Consequently, before its predictions are applied, the nature and limitations of the microbiological dispersion model should be carefully considered.

Applicability of Model Predictions

Spray Irrigation Form

The preceding validation study suggests that the spray irrigation model may be used to predict outdoor microorganism aerosol concentrations near land application systems which use rotating impact sprinklers to apply wastewater that contains no residual chlorine. When the wastewater has a low level of residual chlorine (0.1 to 0.4 mg/l), the model predictions appear to be valid for the standard plate count of aerobic and facultative anaerobic heterotrophic bacteria; presumably they are also valid for the hardier individual microorganisms. With present microbiological aerosol sampling and assay methods, it is generally impractical to sample wastewater aerosols for microorganisms beyond 100 or 200 m from their source. It appears that the spray irrigation model can be used to estimate the aerosol levels of specific pathogens and the traditional indicators to downwind distances of perhaps 400 to 1,000 m from the wastewater spray source, depending upon the precision required in a given application.

As Tables 6, 7, and 8 illustrate, one application of this model is to predict the concentration of potential pathogens inhaled by irrigation workers and residents in the vicinity of wastewater irrigation sites that use sprinklers. Determination of the microorganism doses which subjects inhale (or are otherwise exposed to) during epidemiological studies of the health effects of wastewater aerosols is an application of particular relevance to this symposium; it is discussed further below. Another potential application is to evaluate the public health risks posed by existing and planned land application systems which use sprinklers, relative to those risks posed by other methods of wastewater treatment.

General Form of Model

As Tables 9 and 10 illustrate, the general form of the microbiological dispersion model can be used in combination with limited field sampling programs to predict the distribution of downwind concentrations emanating from other sources of aerosolized microorganisms. These sources include the aeration basins and trickling filters of sewage treatment plants and the cooling towers that circulate municipal wastewater. However, the uncertainties associated with the viability decay rates estimated during the field sampling runs may preclude obtaining realistic model predictions when extrapolating beyond 200 to 500 m from the source.

Factors Limiting Model Applicability

The Viability Decay Rate λ

Distance limitations must be placed on the model predictions primarily because of uncertainty regarding the proper viability decay rate. For rapid viability decay rates and/or for large aerosol ages, the exponential decay term predominates the model calculation of the predicted downwind concentration. To obtain reliable and measurable microorganism aerosol concentrations, field sampling runs to estimate the viability decay rate must be performed so close to the source that only a limited span of aerosol ages can be sampled. Consequently, field sampling cannot detect slow viability decay, and field measurement uncertainties may exaggerate estimates of rapid viability decay. This contributes to the wide distribution of viability decay rates presented in Table 3 and the erratic point estimates obtained using Equation 4. For this reason, only the middle of the viability decay rate distributions given in Table 3 can be recommended for making downwind predictions using the microbiological dispersion model.

Laboratory studies using controlled aerosol chambers can provide more precise and repeatable estimates of bacterial and viral viability decay than can field studies. However, laboratory estimates of viability decay may not be applicable to predictions in the field. The enclosed air traditionally employed in controlled chamber tests in the laboratory produces much slower viability decay in both bacteria (32,33) and viruses (34) than does ordinary outside air. Air pollutants [perhaps the gaseous ozone-hydrocarbon complexes found in smog (35,36)] may cause these bactericidal and viricidal effects. The viability decay rates which Benbough and Hood (34) obtained by exposing laboratory strains to outdoor air for one hour were:

E. coli MRE 162:	-0.00005 sec^{-1} to -0.0008 sec^{-1}
T1 coliphage:	-0.0002 sec^{-1}
T7 coliphage:	-0.0003 sec^{-1} to -0.0005 sec^{-1}
Semliki Forest arbovirus:	-0.0002 sec^{-1} to -0.0003 sec^{-1}

The microorganisms were shaded from direct sunlight in ambient air at relative humidities between 75 and 96% and at temperatures between 2° and 12°C. Even these viability decay rates for open air are much less rapid than the corresponding coliform and coliphage rates obtained from the Pleasanton field study (see Table 3). This may reflect the environmental conditions at Pleasanton which were in many respects more hostile to microorganism survival: solar radiation middle-range relative humidity, generally higher temperature, and wastewater as the pre-aerosolization medium. However, the wide day-to-day variation in the viability decay rates of total coliforms and fecal coliforms at Pleasanton is in agreement with the wide day-to-day variation in *E. coli* viability decay reported by Benbough and Hood.

Selecting Values of I and λ

A reliable procedure is needed for selecting values of the model parameters I and λ when predicting microorganism aerosol concentrations using the spray irrigation model. There are preliminary indications in the Pleasanton data supported by considerable published data (37, 19, 38) that the I and λ values for a microorganism depend upon ambient atmospheric conditions such as relative humidity (19), ultraviolet solar radiation, and temperature (18). A multivariate regression analysis should be conducted to investigate the relationship of I and λ to measured environmental variables such as air temperature, relative humidity, solar radiation, wind speed, air pollutant indices, and wastewater total suspended solids and total organic carbon. If reasonable and consistent predictive regression equations could be developed for at least some of the monitored microorganisms, the predictive ability of the spray irrigation model at moderate downwind distances would be enhanced.

Insights from the I and λ Estimates

The distributions of values of the microbiological parameters I and λ of the model provide insights regarding the monitored microorganisms that are relevant to applied environmental and public health microbiology.

The microorganism impact factor I was intended to represent the fraction of microorganisms that, having entered the aerosol state, survive the shock of aerosolization. Impact factors exceeding 1.0 were not anticipated because such high I values would suggest that more microorganisms survived than the total that were aerosolized. However, perusal of Table 2 reveals that I values above 1.0 frequently occurred. These data suggest that high I values are characteristic of most of the potential pathogens studied at Pleasanton and that I measures additional effects beside initial survival through the aerosolization process. The mechanical splitting of clumped microorganisms into multiple colony-forming units during the processes of aerosolization or sampling is one additional effect which might also be measured by I (21, 19). Underestimation of the pathogen concentrations in wastewater is another possibility (21). Several other less likely possibilities have also been proposed (22).

Comparing the microorganism impact and viability decay values of the different microorganisms indicates their relative ability to survive wastewater aerosolization. By comparing a fixed mid-range percentile (e.g., the 50th percentiles of the microorganism I distributions in Table 2 or the 25th percentiles of the micorganism λ distributions in Table 3), it can be seen that some microorganisms are much hardier than others. The indicator microorganisms commonly used to indicate wastewater pathogenicity (i.e., total coliforms, fecal coliforms, the standard plate count, and coliphage) do not survive wastewater aerosolization nearly as well as do most of the potential pathogens studied (especially human enteroviruses, *Pseudomonas*, and fecal streptococci). Thus, the traditional "microbiological wastewater indicators," especially total coliforms and fecal coliforms, are actually very poor indicators of the pathogenic hazard posed by wastewater aerosols. The use of most of the traditional indicator organisms in field studies to monitor wastewater aerosols may result in unrealistically low estimates of the aerosol levels of potential pathogens.

On the other hand, fecal streptococci may be a better indicator for wastewater aerosol monitoring (39) due to the relative ease of their assay, their prevalence in wastewater, and their survival through wastewater aerosolization and in the aerosol state. However, because fecal streptococci are frequently present at variable levels in background aerosol samples, the detection of low levels of aerosolized fecal streptococci downwind does not necessarily implicate the investigated wastewater aerosol as the source of the sampled fecal streptococci.

Use of the Model to Estimate Human Exposure to Wastewater Aerosol Microorganisms

The process by which the viable airborne microorganisms in wastewater aerosols are inhaled and initiate infection may involve as many variables (40,41) as does the aerosolization and transport process. The dose of viable microorganisms that are inhaled can be estimated using the microbiological dispersion model as outlined below. However, the limitations of dose estimation should be recognized so that calculated inhaled doses are given suitably modest interpretations.

Inhaled Dose

The dose of a specific airborne microorganism from a wastewater aerosol source that is inhaled by a person in the vicinity during the time interval $t = t_0$ to $t = t_1$, may be estimated from an integral (16):

$$\text{Inhaled Dose} = \int_{t_0}^{t_1} P(t)\,(\text{Breathing Rate})\,dt, \qquad \text{(Equation 7)}$$

provided the microbiological dispersion model prediction P(t) follows the person's movement throughout the time interval (i.e. P(t) is the predicted air concentration at the person's location at time t).

Examples of a simplified calculation of the approximate highest daily dose inhaled in a year by children attending the school next to the Durham plant are given in another symposium paper (27).

Limitations of the Dose Estimate

It would be desirable to calculate the dose of the specific agent responsible for the illness or infection being investigated. However, percentiles of the model parameters I and λ are available only for the groups of microorganisms shown in Tables 2 and 3. For example, if seroconversion to Echovirus 29 were occurring in the nearby population, one could only use the I value for the entire group of enteroviruses and would be forced to guess a value for λ. Furthermore, there are analytical difficulties in determining the concentration W of a specific agent in wastewater (42). Consequently, the dose estimates will generally apply to a group of microorganisms which includes the specific agent of interest.

It is difficult to calculate P(t) accurately. The limitations of the microbiological dispersion model predictions are discussed above. In addition, a person is a very mobile receptor. His path of movement during the period under investigation is often impossible to reconstruct and is difficult even to characterize, unless he has kept an hourly log or daily diary of his activities. Another complication, usually of lesser significance, is temporal variation in the wastewater aerosol source strength due either to periodic operation or to diurnal fluctuations of the source.

Most people spend the majority of their time indoors. This simplifies the "mobile receptor" problem, but introduces another. The parameters of the microbiological dispersion model are based on field studies of outdoor aerosol concentrations; its predictions are presumably applicable to exposure outdoors rather than indoors. In some situations, indoor doses may approximate outdoor doses. Spendlove (43) found that the aerosol dose of a hardy microorganism received by inhabitants within a single-story residential dwelling without airconditioning is essentially the same as outside the building, presumably when the outdoor concentration is high and relatively constant over time periods exceeding 1 hour.

When inhaled, the size of a microorganism-laden aerosol particle affects the depth of its penetration into the respiratory tract (40). Depth of penetration influences the likelihood of infection. Field sampling studies of wastewater aerosols (29, 20) have shown that the majority of particles containing microorganisms are in the range of pulmonary deposition (less than 5 μm in diameter) and that viable particles are distributed throughout the respirable range.

From a public health perspective, it is desirable that the dose computed be the number of *infective* microorganisms, (i.e., those capable of invading the host and proliferating to initiate infection). However, Equation 7 utilizes the microbiological dispersion model prediction which is based on air and wastewater sample assays for the microorganism. Thus, the dose calculated from Equation 7 is the number of *viable* microorganisms (i.e., those capable of *in vitro* reproduction). Laboratory studies suggest (16) that the environmental stresses associated with aerosol aging may damage aerosolized microorganisms so that their infectivity sometimes diminishes more rapidly than their viability.

Feasible Applications in Population Studies

In light of the limitations just described, it is suggested that use of inhaled doses calculated using the microbiological dispersion model and Equation 7 be cautious and judicious. Applications that utilize the calculated doses merely to rank the level of human exposure appear to be more tenable than those based on the calculated magnitude of the dose. In population studies of infectious disease health effects, there are several feasible applications.

The dose inhaled by each human subject or each household of subjects can be estimated from Equation 7 in order to classify the subjects into several groups based on the calculated level of their wastewater aerosol exposure. The health responses (whether symptomatic, serologic, or clinical) among the subjects can then be analyzed both within groups and between groups to investigate possible dose-response relationships.

Another potential application is in etiologic case studies of infectious-disease outbreaks which may have a wastewater aerosol origin. A diary of activities that recorded unusual exposure situations might be a prerequisite for the calculation of inhaled dose to be useful in such etiologic investigations.

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DISCUSSION

DR. SPENDLOVE: Dave, I think you have done a wonderful job in trying to pull together a number of parameters. I suggest that you include a penetration parameter.

MR. CAMANN: Yes, I believe you have done some work on that in the biological warfare program. We are planning to do that in future studies in order to get a handle on it.

DR. SPENDLOVE: I can give you a reference on a model that I worked on with penetration, if you are interested.

MR. CAMANN: Yes, I am.

DR. SPENDLOVE: I thought that your reason for impact factors exceeding one was right on line. Of course, we are dealing with a situation here that does not have a negative I index, and I think that it is easy to explain why you get a high value with a breakup in the particles.

MR. CAMANN: Yes. That could be true. We have identified about five possible hypotheses, that being one of them. We have no basis for choosing among them at this point.

DR. SPENDLOVE: The other thing: your E values seemed awfully strong to me, for spray irrigation particularly. Did you define those on the basis of respirable particles?

MR. CAMANN: No, this was based on the use of a dye tracer and the assumption that the microorganisms had the same characteristics of aerosol formation as did the dye. A rotamine WT dye was used in the Pleasanton study. I am not sure which dye they used on the Army studies.

DR. SPENDLOVE: Generally, efficiency is based on the percentage of respirable particles that are produced.

DR. FANNIN: I am wondering if you feel that with the unexpected I value of 40 for the enterovirus, it is appropriate to make any prediction as to the enterovirus concentration at the distances that you predicted.

MR. CAMANN: I did put an approximation on the 40 because it is only based on two aerosol runs, one of which gave a value of I of approximately 10, I believe, and the other, approximately 70. So it is quite an approximation. The problem is that it takes a very extensive aerosol monitoring program to come up with any value, and we simply do not have enough data to be sure of the true value.

DR. WARD: I assume that this is probably one of your five explanations, but I think about a year and a half ago an article came out in Science that suggested that microorganisms are concentrated to higher magnitude in the spray. Are you aware of that article?

MR. CAMANN: I am not aware of it. I would like to see it. In talking to various people we have been speculating on various reasons since we have started finding these values higher than one. I do have a summary of these five hypotheses in one of my papers.

DR. FLIERMANS: How do you deal with the virulence factors associated with these various organisms? An organism that has recently passed through a host of some sort is more virulent than one that has not. How do you deal with that in the model?

MR. CAMANN: I have not attempted to deal with that, as you can see. We are more or less just taking what comes out of an aerosol source and projecting that into an exposure setting. As far as the virulence factor goes, I have not tried to work in anything on that.

DR. LUE-HING: What was the population of viruses in the sewage work?

MR. CAMANN: I would have to defer to Chuck Sorber. It was just a wastewater sample and a measurement of total enteroviruses, I believe.

DR. SORBER: The mean virus concentration in the wastewater that was sprayed was 17 pfu/l. There was quite a range on it.

DR. SPENDLOVE: Regarding the virulence question, of course this is an extremely complex parameter to have to deal with, there has been some work with it. They have to be studied with each individual organism. There has been considerable work done with *Pasteurella tularensis*, as some of you may know, and models that deal with that concentration downwind deal with it in virulence decay situations, the same as viability decay. Of course the virulence does decay with travel downwind, with that particular organism. I am assuming it also decays with the intestinal organisms in very much the same way.

DR. SCHAUB: One of the things I am encouraged about from this particular study that Dave has done is that an individual source, a line source, and a field source were actually looked at after the model was set up, and there was at least within an order of magnitude capability in predictability of the aerosol dispersion. I think that is significant. I think we are making progress in terms of identifying the downwind migration of these aerosols.

DR. LUE-HING: When we make predictions of aerosols, the people who have to relate to them are somewhat out of practice. State how imprecise some of the data are. When you write your conclusions you certify what that means. If they mean nothing don't write them, because if you do, somebody will believe them and use them.

MR. CAMANN: I think the point that has to be raised, though, is that we have to start quantifying doses. In the case studies that will be presented, we need to start quantifying doses even if they are very approximate and indicate the uncertainty in the measurement; but when we have health effects or no health effects, we should give some idea of the dose of exposure that we are talking about, whenever possible. I agree that we definitely need to spell out how imprecise those numbers are.

DR. LUE-HING: I am glad you agree. It is meaningless except if an expert wants to use it.

Infection and Resistance: A Review

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ABSTRACT

The relationship of infection and host defenses has provided much of the impetus for the development of the science of immunology. Leukocytes play a central role in determining the status of a host's ability to defend against or control infection in collaboration with a variety of serum proteins. Defective function in any one of three types of white cells, the polymorphonuclear leukocyte, the lymphocyte, or the phagocytic mononuclear cell, has been associated with a distinctive pattern of infection. In addition, congenital and acquired deficiencies of serum complement increased vulnerability to infection. The objective of this presentation is to review the function of these cells and proteins and current concepts of host resistance to infection.

Historically, attempts to develop means of prevention and treatment of diseases due to microorganisms provided the stimulus for the science of immunology in the 19th century. With increased knowledge of the relationship of the host to bacteria, it is recognized that parasitism of a host can result in a symbiotic relationship, destruction of the parasite, or death of the host and subsequently of the invading microorganisms. The determinants underlying the outcome include host mechanisms, which distinguish self from nonself, and protective or "virulence factors" evolved by microorganisms which enhance their survival.

Disease results if virulence factors overwhelm host defenses and, paradoxically, as a consequence of the host's recognition of nonself. Thus, tissue injury can be produced by the inflammatory and immune response evoked by bacteria, fungi, or viral invaders. For example, the initial parasitism by the dengue virus results in a relatively mild illness but provokes an immune response which is responsible for a serious illness with hemorrhagic complications, shock, and a high mortality following a second infection with a serotypically related but different dengue virus (1).

The specific immune response is genetically determined (2). In addition, alterations in immunity are associated with age. Successful influenza vaccination may require two inoculations in the elderly (3,4), and immunization with bacterial polysaccharide vaccines is less successful in children under 12 months of age (5). The nonspecific inflammatory response is also altered with age, intercurrent disease or therapy, and by specific genetically determined abnormalities.

Unique characteristics of a specific parasitic and host interaction also determine production of illness. Thus a lower inoculum of *Salmonella* *typhosa* will result in typhoid fever in the unimmunized host than in the immunized individual (6).

Resistance to infection is determined, therefore, by multiple factors, and although this presentation will examine in detail the cellular response to infection, it must be emphasized that nonspecific barriers are also important components of resistance. Such barriers include skin, mucous membranes, respiratory epithelium, and gastric acid. Breaks in these barriers due to trauma, surgery, disease, or environmental toxins increase susceptibility to infection.

Host responses to microorganisms which have breached the external barriers are dependent upon a diverse group of cells, the leukocytes. Defective function of any of three cells, the polymorphonuclear neutrophil, the lymphocyte, or the monocyte (macrophage), has been associated with specific patterns of infections. Defects in number and function of these cells and the infections associated with these deficiencies will be discussed. For purposes of presentation, each cell will be considered separately, but it is good to emphasize that the response to infection involves a complex interaction of all three cells, their function, and their extracellular products.

THE POLYMORPHONUCLEAR NEUTROPHIL (PMN)

The PMN, an efficient phagocytic cell, is central to the host's ability to control infection by bacteria (7). To accomplish the task of disposing of invading microorganisms, PMN must be produced in adequate numbers by the bone marrow, enter the vascular space, leave the intravascular compartment, and arrive at the site of bacterial invasion. The peripheral blood contains the majority of neutrophils available for delivery to tissue. Approximately one-half to two-thirds of these cells are in the so-called marginal pool and are not detected by the usual white blood counts. The neutrophils of the marginal pool cross the endothelial lining of the vascular bed, enter the extravascular space, and emigrate to tissue sites invaded by bacteria. Adherence of neutrophils to endothelial cells is necessary before this diapedesis occurs (8). Neutrophil adherence is enhanced in disease states and is characterized by inflammation; conversely, adherence is depressed when patients are receiving anti-inflammatory agents or after acute ingestion of alcohol.

In vivo inflammatory stimuli produce an emigration of PMN and mononuclear cells into tissue. The normal entry of leukocytes into a skin window is sequential: after a latent period of two hours, PMN are first noted; by 12 hours, the peak PMN response is achieved; and by 24 hours, the predominant cell is mononuclear. Entry of neutrophils to an area of inflammation is depressed in neutropenic states (less than 1500/mm^3), leukemia, acidosis, with corticosteroid therapy, and following acute alcohol ingestion (9,10,11).

Once in the tissue space, PMN, which are motile, must be attracted to the site of microbial invasion. This directed response is determined by the cell's ability to detect and respond to chemotactic stimuli. Such stimuli are generated by most bacteria (12) and by soluble factors produced as a result of complement activation (13). In certain families, deficiencies of the complement components C3 and C5 have been associated with repeated infections (14). These patients may be thought of as having a defective chemotactic response due to abnormalities in the milieu in which the PMN must function. Similar complement deficiencies and defective neutrophil responses have been noted in cirrhotic patients (15). Production of circulating inhibitors of PMN chemotaxis have been demonstrated in the serum of patients with Hodgkin's disease and carcinoma of the lung (16). In addition, children with eczema, excessive circulatory IgE, and impaired leukotactic responses thought to be due to the effects of histamine on PMN motion have been reported (14). In contrast to these humoral perturbations, intrinsic abnormalities of neutrophil function have been described in children with the lazy leukocyte syndrome, in diabetics, and in near relatives of diabetic patients whose cells do not respond to chemotactic stimuli (14).

Neutrophils, once in contact with the invading microorganisms, must engulf and subsequently kill the invader intracellularly. Phagocytosis of some microorganisms, classically encapsulated pyogenic organisms, requires the presence of adequate serum opsonins, such as specific antibody (see below), or complement, or both (7). Poor opsonization has been associated with defective conversion of the third component of complement by insulin, a measure of the alternate complement pathway function. C3- and C5- deficient kindreds are vulnerable to gonococcemia and meningococcemia (14). Sera from patients with a deficiency of C2 poorly support phagocytosis of *Staphylococcus aureus* while continuing to provide adequate opsonization of the gram-negative bacterium, *Escherichia coli* (17). This recent observation and other studies emphasize the complex relationship between specific components of the opsonic, phagocytic, and bacterial systems (18).

The killing of bacteria by PMN involves both oxidative bactericidal mechanisms and release of cationic proteins from cytoplasmic granules into the phagolysosome containing the bacteria (7). The oxidation mechanisms involved include uptake of O_2 and of glucose, a production of CO_2, H_2O_2 (singlet and superoxide), and the fixation of a halide by the enzyme, myeloperoxidase. *In vitro* killing of ingested organisms is accomplished within minutes; digestion is a longer process.

Characteristically, deficits in number or function of the PMN results in infection by *S. aureus*, endogenous aerobic, and anaerobic gram-negative bacilli or fungi. Pneumonia, visceral abscess, perirectal abscess, deep pharyngeal infections, and bacteremia are common. If the defect is not transient, these infections recur. Successful treatment requires adequate surgical drainage when possible and prolonged courses of bactericidal antibiotics.

THE LYMPHOCYTE

The lymphocyte has been established as the major cellular element in the immune response. Schematically, two populations of lymphocytes have been delineated: immunoglobulin-(antibody) secreting cells (B-cells) and the thymus-dependent cells (T-cells) (19). Thymus-dependent cells mediate host-versus-graft reactions, contact-sensitivity reactions, and other manifestations of cellular immunity. Certain T-lymphocytes also can function as helper cells in the production of antibody by B-lymphocytes. T-lymphocytes also regulate the immune response through suppressor effects and production of lymphokines which modulate macrophage function.

B-CELLS

Immunoglobulins, the secretory products of B-lymphocytes, exist in a variety of classes in serum and in body secretions. IgG and IgM appear to mediate the majority of immune reactions concerned with defense against microbiologic agents such as opsonization, complement fixation, and viral and toxin neutralization. Specific IgA, induced by infection or local immunization, prevents adherence of virus or bacteria to mucosal surfaces (20). The function of IgD is unknown, but it may act as a surface receptor on B-lymphocytes that combines with antigen to trigger specific antibody production (21). Reagin of IgE mediates immediate allergic reactions by triggering the release of vasoactive substances from mast cells following interaction of allergens with specific mast cell-bound IgE. It has been postulated that its defensive role is to control parasitic infection or to amplify host responses to foreign antigens crossing mucosal surfaces.

The underlying cause of the wide variety of B-lymphocyte deficiencies varies (14). In X-linked hypogammaglobulinemia, there is an absence of B-lymphocytes. In contrast, some cases of common variable immunodeficiency appear to be the consequence of overactive suppressor cells, which depress B-lymphocyte function. In addition, a few children with defects in purine metabolism, transcobalamin II deficiency, and hypoxanthineguanine phosphoribosyl transferase (Lesch-Nyhan syndrome) have been described with B-lymphocyte abnormalities. The infections seen with hypogammaglobulinemia are classically those in which antibody is required to overcome bacterial-antiphagocytic factors such as the capsular polysaccharide of *Haemophilus influenzae*. Secondary hypogammaglobulinemia occurs with chronic lymphocytic leukemia, the paraproteinemias, multiple myeloma, and some cases of non-Hodgkin's lymphoma.

T-CELLS

Thymus-dependent lymphocytes make a complex contribution to host defense (23). Cooperation between T- and B-cells is required for maturation of antibody production by B-cells, i.e., the production of IgG following initial secretion of IgM. IgA and IgE also require interaction between T-helper and B-cells. Some antigens such as polysaccharides are thymus-independent and elicit antibody responses in the absence of T-B-cell cooperation, however, the majority of microorganisms with their complex structure induce thymic-dependent immune response. A subset of T-cells inhibit antibody production. Other T-cells suppress effector functions of T-lymphocytes. The role of suppressor T-cells in mediating tolerance to foreign antigens and enhancement of tumor or homograft survival remains under investigation (24).

In vitro sensitized T-lymphocytes produce, upon appropriate antigenic stimulation, a number of soluble factors, the lymphokines, which are thought to mediate cellular immunity (22). The biologic significance of these products is thought to be an amplification of host recognition of a foreign antigen. It has been demonstrated that few specifically sensitized lymphocytes (less than 5% of the total cells involved) provoke a significant inflammatory response upon challenge by antigen. This amplification is theoretically mediated by the soluble products of T-lymphocytes, which attract macrophages, retain them at the appropriate site, and increase their bactericidal capacity. These effects are nonspecific and have been shown to affect macrophages derived from nonsensitized hosts. Other lymphokines attract neutrophils. In addition to interacting with phagocytic cells, lymphokines have been identified that induce a mitogenic response in nonsensitized lymphocytes, thus providing more cells at the immunoinflammatory focus. A transfer factor converts nonsensitive lymphocytes to an antigen-responsive state, again amplifing the response. Finally, T-lymphocytes release interferon, an antiviral substance, either following exposure to specific antigens or nonspecifically, following exposure to mitogens. Defects in thymus-dependent responses are due to multiple causes (14). Congenital thymic aplasia (the DiGeorge syndrome) represents a failure of normal embryologic development of the thymus and parathyroid glands from the third and fourth pharyngeal pouches. The prototype of a combined T- and B-lymphocyte disorder, severe combined immunodeficiency disease, in contrast to the DiGeorge syndrome, represents failure of the stem cell of both T- and B-lymphocytes to differentiate normally or, alternatively, represents a deficiency of the enzyme adenosine deaminase. Depressed cellular immune responses are also found in a number of neoplastic diseases. Hodgkin's disease represents the best example of a neoplastic disease in which T-lymphocyte dysfunction has been demonstrated. Similar depression has been noted in disseminated infections due to intracellular organisms, such as in lepromatous leprosy, tuberculosis, and histoplasmosis. Acute viral and pyogenic bacterial infections have been associated with transient dysfunction of T-lymphocyte responses. Lack of *in vitro* lymphocyte responsiveness and depressed skin reactivity have been noted in aged individuals and patients with protein-calorie malnutrition.

Infection by intracellular pathogens such as fungi, herpes virus, and mycobacterium result from depression of cellular immunity. Correlation of T-cell dysfunction and such infection has been clearly established in Hodgkin's disease, in patients receiving cytotoxic therapy for neoplastic disease, or in patients receiving immunosuppressive therapy to control host-versus-graft reactions. Iatrogenic interference with cell-mediated responses has been one of the major limitations of cytotoxic and immunosuppressive therapy.

THE MONONUCLEAR PHAGOCYTE

The third cell that is involved in host defenses against microorganisms is the phagocytic monocyte or macrophage (25). These cells, which are derived from the bone marrow, are located in the peripheral blood (monocytes) or in tissues (macrophages). They are fixed in specific organs, lining the sinuses of liver and spleen and the pulmonary alveoli. Monocytes can leave the vascular compartment, enter the tissues, and participate in cell-mediated reactions described above. With appropriate stimulation, the number of mononuclear phagocytic cells in the liver can be greatly expanded by both proliferation and recruitment of blood monocytes.

Macrophages have receptors for IgG and complement that enhance adherence of opsonized particles and facilitate ingestion. They also are capable of nonimmune phagocytosis. Phagocytosis and ingestion of antigen by mononuclear cells presumably play important roles in the preparation and presentation of antigen to lymphocytes, a precondition for the immune response. In addition, macrophage products or cell-to-cell contact between macrophages and lymphocytes facilitates lymphocyte responses to antigen and to mitogens.

Mononuclear cells produce a metabolic burst following ingestion of bacteria, which is dependent upon hexose monophosphate shunt activation. Killing of bacteria in these cells may involve H_2O_2 production and fixation of halide as in PMN. Enzymes in macrophages include hydrolases, also found in PMN, which are involved in the digestion of macromolecules. The cationic proteins of neutrophils, which are bactericidal, are lacking.

Certain bacteria have evolved the ability to survive within macrophages. The tubercle bacillus, for example, can survive and replicate intracellularly. Other organisms also resist killing unless coated with antibody; this emphasizes the intimate relationship between lymphocytes or products of lymphocytes and the phagocytic mononuclear cell.

Dysfunction of the mononuclear leukocytes has been demonstrated in chronic granulomatous disease, in certain hematologic neoplasmas, in malacoplakia, and in association with corticosteroid therapy. Disseminated infections due to intracellular pathogens may represent an example of intrinsic dysfunction of this system of phagocytes. However, a failure of macrophage-lymphocyte interaction, or a lymphocytic defect, could mimic an intrinsic defect in macrophage function.

Diseases that are associated with proliferation of monocytes, as manifested by peripheral blood monocytosis or enlargement of the spleen and liver, include chronic infections such as subacute bacterial endocarditis, tuberculosis neoplastic disease such as Hodgkin's disease or myelomonocytic leukemia, hemolysis, inflammatory bowel disease, collagen vascular disease, and chronic diseases associated with granuloma formation of unknown etiology. The nature of the stimulus causing the hyperplasia of this cell type is unknown.

RELEVANCE OF CELL DEFECTS TO INFECTION

Increased understanding of the function of PMN, lymphocytes, and mononuclear phagocytes has emphasized the complex nature of host defenses. Although patterns of infection can be associated with a specific defect, the most common clinical problem is infection in a host with a combination of defects. Thus, the patient with Hodgkin's disease may have depressed T cell function and be receiving cytotoxic agents which induce neutropenia and corticosteroids which alter PMN and mononuclear cell function In addition, the patient may be malnourished secondary to anorexia and be receiving treatment through an intravenous line which provides a portal of entry for bacteria. Less dramatically, elderly patients have alterations in cellular immunity, changes in immunoglobulins, a poor response to vaccination, and depressed PMN function.

The number of conditions or diseases associated with alterations in host defense mechanism is long and becoming longer (14). The challenge is to relate clearly the *in vitro* demonstration of a defect with increased susceptibility to infection and to find acceptable methods for correcting the relevant deficiency.

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Infection with Minimal Quantities of Pathogens from Wastewater Aerosols

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ABSTRACT

Raw wastewater invariably contains human pathogens. These pathogens are a threat to public health to the degree that: 1) susceptible people are actually exposed to them; 2) an infection results from the exposure; and 3) disease results from the infection. To be considered in the present discussion, the pathogen must also have been disseminated in an aerosol at some point between the raw sewage and the susceptible person. Of the human pathogens which occur in aerosols from sewage treatment or application, some may be capable of infecting directly upon inhalation. More concern has usually been directed to the potential deposition of airborne pathogens upon food crops or on other surfaces to which people are exposed. Few data indicate that people have actually become ill because of aerial dissemination of pathogens from wastewater; however, negative epidemiologic evidence is even less persuasive than most other kinds of negative evidence. Prudence dictates that people should not venture closer than necessary to a source of wastewater aerosol, yet people visiting sewage treatment plants regularly stand in the aerosol cloud of the activated sludge tanks without perceptible ill effects. Wastewater probably should not be sprayed directly onto vegetables that are to be consumed by humans, but aerosols (in the strict sense of the word) apparently are not a very efficient means for disseminating wastewater-borne pathogens.

This symposium is evidence of the concern that exists regarding health hazards associated with wastewater aerosols. Aerosols are a result of using some effective and energy-efficient methods of wastewater treatment and disposal. Concern over health hazards seems to have been based largely upon some worst-case assumptions about the effects of exposure to aerosols. In addressing my assigned topic, I do not intend routinely to assume the worst case.

PATHOGENS IN WASTEWATER AEROSOLS

The domain of this paper is the dependence of human infection and disease upon dose, where the infectious agent is present in a wastewater aerosol. The infectious agents which are in wastewater and may be a threat to human health are essentially those produced in the human intestines. These agents occur in wastewater through the agency of the water carriage toilet, which itself generates aerosols when flushed (1,2). It seems clear that this and virtually all subsequent chances of disseminating pathogens in wastewater aerosols could be avoided if an alternative to the water carriage toilet could be developed for feces disposal.

Levels of Pathogens in Wastewater

If feces are carried by wastewater, then bacteria, viruses, and protozoan and metazoan parasites are likely or certain to be present, depending on the size of the population served and, to a limited extent, the season. The incidence of most of these agents in human feces has been quite thoroughly summarized by Geldreich (3). The dilution factor for feces in household or community sewage will fall somewhere in the range of 1,000 to 10,000. The derivation of these factors will not be discussed here, but it does seem worth noting that the ten-fold range of uncertainty that is included here is at least as precise as the estimates for the levels of most organisms in the feces themselves. For organisms which are part of the normal intestinal flora, initial numbers in sewage should be lower than those in feces by factors of 1,000 to 10,000. Because any given pathogen is absent from the intestines of most members of a community on any given day, the initial level of the pathogen in sewage must be estimated from the level of the pathogen in positive stools, reduced by the dilution factors just quoted, and reduced further by the proportion of the donor population that does not harbor the agent in question. A pathogen present in the feces of 1 to 10% of members of a community at a level of 10^8/g might occur in raw sewage at levels of 10^5 to 10^7/l.

Wastewater Aerosols

In a properly designed and operated sewer system, the raw sewage spends relatively little time in transit between the source and the treatment plant. The actual time might range from an hour to something less than a day, depending on the size of the system. There should be little microbial action or loss of sediment during that time, though a small loss of pathogen titer might occur at the moderate temperatures of sewage. Any aerosols produced in transit would be a risk only to those whose occupation took them into the sewers.

The foci of attention, from the standpoint of aerosol production, must be the sewage treatment plant (principally during aerobic secondary treatment) and disposal sites where spray application is practiced. Aerosol generation and decay are the domain of others at this symposium. A few brief generalizations will suffice here. First, pathogen levels in wastewater during secondary treatment may be only slightly less than those in raw sewage, whereas those in treated wastewater or digested sludge at an application site should be significantly reduced. Also, the degree of exposure to the aerosols should generally be greatest for workers at the site, less for visitors to the site, and less still for those who live near the site.

INFECTION VIA AEROSOLS

Persons exposed directly to aerosols might become infected either because inhalation led immediately to a respiratory infection or because respiratory mucus laden with trapped pathogens was swallowed so that infection took place in the digestive tract. Aerosols might also settle on food or water and lead to infection via the digestive tract. With the possible exception of *Mycobacterium tuberculosis*, few agents which can infect the lungs are known to occur with significant frequency in sewage. A few of the enteric viruses in sewage may be able to infect the upper respiratory tract. However, it appears that sewage aerosols have principally to be considered yet another of the many means by which fecal-oral transmission of enteric pathogens may occur.

One can follow this train of assertions to the conclusion that a given quantity of pathogen in a sewage aerosol should represent a threat to public health no greater than that of the same quantity of pathogen ingested with any vehicle. A possible exception to this is the finding of Darlow et al. (4) that lethal infections in mice were produced by considerably smaller doses of *Salmonella typhimurium* when inhaled than when ingested. The conclusion drawn is undoubtedly valid, but it may well be irrelevant to human health. Pulmonary salmonellosis is virtually unknown in humans, although those who work in the poultry industry must have their respiratory tracts challenged even more frequently with airborne Salmonella spp. than with the agent of ornithosis, which is frequently transmitted to them in this way.

If enteric pathogens are not uniquely infectious by the aerosol route, then any available data on peroral infectivity of these agents should be pertinent to the present question. There are at least some data for bacteria, viruses, and protozoa. Most of the controlled experiments that have been reported were done with healthy young men as subjects; the results may be applicable to the rest of humanity only with some reservations. A few incidental reports are also worth noting.

Infection

Infection can be defined as the establishment and propagation of an agent in a host. Infection by an enteric agent can frequently be confirmed by showing that more of the agent is shed in the stool than what was originally fed to the host; infection can also be inferred if the host begins to produce antibodies against the agent that was administered. An infectious dose of an agent is the quantity that produces infection.

Disease

For the present discussion, disease can best be defined as a state of abnormality that results from infection of a host. The ability of an infectious agent to induce disease in a host may be called virulence or pathogenicity, and the process of disease production is termed pathogenesis. One might define the pathogenic dose of an infectious agent as the quantity that produces disease. For nonpathogenic species and for attenuated agents such as the oral poliomyelitis vaccine viruses, there should be no such thing as a pathogenic dose; an infinite quantity of the infectious agent should fail to produce disease in the infected host. At the other extreme, there are agents (not necessarily of enteric origin) so virulent that virtually every infection will induce at least some significant abnormality in the host. Many agents produce infections that give rise to illness only on occasion. One might well suppose intuitively that pathogenesis by such agents is dose-dependent, i.e., that some larger quantity of the agent is required to induce disease than that which produces infection. As it happens, I have been unable to find clear experimental evidence that this is true for any agent which might infect via wastewater. It appears, instead, that the likelihood that infection by one of these organisms will result in disease depends upon the interaction of the agent's virulence, the host's resistance, and chance, but probably not to any significant degree upon a dose greater than that which sufficed to produce infection.

Host Factors

The human body is more complex than any of its parasites, so it is not surprising that a great many determinants of the host-parasite relationship originate in the host. Despite the acknowledged significance of these host factors, most of them are as yet poorly understood. A brief survey of the scope of these seems appropriate, but any extensive discussion would likely consist more of platitudes than of facts.

Protozoan parasites and the majority of enteric bacteria and viruses show a high order of species and tissue specificity. Recognition factors for viruses may consist of specific receptors on the plasma membranes of appropriate host cells, but other factors are undoubtedly also involved. The means by which enteric bacteria and protozoan parasites of man recognize distinctive features of the environment in the human intestines as correct are largely unknown. This is unfortunate, inasmuch as the practical importance of these phenomena to sewage treatment and disposal is enormous. More research on the subject is certainly needed, but it will be very difficult to do because use of human subjects is increasingly constrained, and research with any nonhuman species is subject to criticism for that reason alone.

Immunity, another major host factor, has come to be relatively well understood in recent years. That is, a great deal has been learned of how an infectious agent evokes a humoral or cellular immune response in a host. The immune response to an enteric virus infection may provide the host with relatively solid and durable protection against that type of virus, perhaps for the life of the host. Immunity against enteric bacteria is apparently less durable, and the immune response against protozoan parasites evidently offers relatively little protection against reinfestation.

Between the species and tissue specificity factors (which are innate and more or less constant) and immunity (which is acquired after experience with an infectious agent) there is a spectrum of factors categorized as "resistance." Though resistance has meaning only in relation to infectious agents, resistance is presumably something the host either does or does not have before the encounter with an infectious agent. Resistance to infection may be enhanced by the presence in the host of a competing normal microbial flora and may be diminished by the presence of a second infectious agent. Most aspects of resistance are very poorly characterized: some appear to be intrinsic to the host's own organism, whereas others are said to be derived from such exogenous sources as chicken soup. Stress and nutrition are undoubtedly influential.

Specificity and immunity are probably the host factors most effective in determining whether an infection takes place; whereas the resistance factors, and in some cases immunity, are the principal determinants of the course of an infection once it has begun. All of the agents under consideration here infect by way of the digestive tract. Some may remain there and cause disease, but others must work their way from the digestive tract to other parts of the body if disease is to ensue. Therefore, the outcome of an infection by one of the latter type agents may be determined by how effectively the infection is confined to the intestines, rather than by how rapidly the body suppresses the infection entirely. It is this least-characterized category of host resistance factors that I believe includes the major determinants of whether infection by a pathogen results in disease.

PERORAL INFECTION WITH MINIMAL DOSES

Studies of peroral infection by bacteria and viruses have been surveyed elsewhere (5). I shall cite a few studies here but will not attempt an exhaustive review.

Bacteria

The genus *Salmonella* has attracted much attention because it is relatively frequently transmitted through food and water. Early studies had indicated that *Salmonella* infection would usually result only if millions of viable cells were ingested, but more recent research has demonstrated infections with smaller doses in some instances. A study in which *S. typhi* was fed to volunteers makes the unfortunate error of reporting results in infectious doses when the text makes it plain that those who were infected but not ill were scored as negative (6). Rates of illness observed at different numbers of organisms administered were 0% at 10^3, 28% at 10^5, 50% at 10^7, and 95% at 10^9. Typhoid is a systemic disease; in the light of what was said above concerning host factors and pathogenesis, it is perhaps significant that the ten thousandfold increase in dose from 10^5 to 10^9 produced a reduction of median incubation period from 9 days to 5 days, which may not have been significant in view of the wide ranges quoted for the incubation periods in each group.

S. cubana, present as a contaminant in a carmine dye (7) preparation used to measure intestinal transit times on a hospital ward for patients with gastrointestinal problems, caused illness when approximately 15,000 cells were ingested. Unlike those used as research volunteers, these people spanned a great range of ages, and many were debilitated by another existing illness before they ingested the *S. cubana*.

A more normal sample of the public was recently exposed to chocolate easter eggs and rabbits contaminated with *S. eastbourne* (R. H. Deibel, Department of Bacteriology, University of Wisconsin-Madison, personal communication, 1979). Healthy adults and children developed *Salmonella* gastroenteritis after eating candy contaminated with levels of <1 to 100 organisms/100 g.

Infection and disease may follow ingestion of very small numbers of *Shigella* organisms. In volunteer studies, the numbers of subjects infected or made ill by small doses of highly virulent *Shigella flexneri 2A* were roughly comparable (8). About 25% were infected and made ill after ingesting 180 cells; infection rates were roughly level, in the range of 50 to 70%, with doses of 5,000, 10,000, and 100,000 organisms. Despite the extreme infectivity and virulence of this organism, it appears that at least 30% of the volunteers were insusceptible to it. This insusceptibility was presumably the result of previous exposure to the organism (or to one of its immunologic relatives); yet the presumed prior exposure must not have resulted in a high level of humoral antibody, inasmuch as serum antibodies were measured, and a high level of preexisting antibody would almost certainly have disqualified a volunteer from participation in the study. Host factors, yet to be defined, were undoubtedly at work.

In a study that involved smaller numbers of subjects, one out of 10 subjects who were fed cells of an invasive strain of *Shigella dysenteriae 1* became ill (9). The proportion of subjects made ill appeared to increase with larger doses, but one of six who received 10,000 cells (the highest level of this strain administered) remained well. Infections unaccompanied by illness were recorded as negative results; doses of 10^6 or more cells of noninvasive strains were said to have been tolerated. Mean incubation periods were reported for illnesses caused by the invasive strain and did not appear to vary as a function of dose over the range tested.

Two invasive strains of enteropathogenic *Escherichia coli* were used in another human volunteer study (10). The results are somewhat difficult to evaluate because of the style of reporting. One strain caused infections in some of the recipients of doses of 10^4 and 10^6 cells, but disease was not seen with doses less than 10^8. The other strain appeared to be less infectious but more virulent. This study is the only one of those considered which seems to show some indication of a dose effect in pathogenesis. Unfortunately, one of the experimental groups seemed to have included more ill persons than could be shown to have been infected by the criteria that were applied.

It appears that there are bacteria which can occasionally cause infection and disease upon ingestion of 10 organisms or less. With other species, infections were seen only in persons who had ingested at least 10^4 organisms. However, given the small numbers of persons involved in a human volunteer study, it may be that if an infection resulted when one subject ingested 10,000 organisms, one infection would also have resulted among 10,000 persons, each of whom ingested one organism. There are ordinarily fewer illnesses than infections, but this does not necessarily indicate that more organisms must be ingested to cause disease than the number that causes infection. Where more illnesses than infections are seen, some skepticism is in order.

Viruses

Human volunteer studies of peroral infection with viruses have been done quantitatively only with vaccine polioviruses. Even so, the quantities of virus administered have been expressed in terms of tissue culture infectious doses which bear an uncertain relationship to numbers of viral particles. The studies done with vaccine polioviruses afford only slightly more accurate estimates of virus dosage than studies with Hepatitis A in which dosages were expressed as dilutions of infectious human stool. The vaccine polioviruses are attenuated to a degree that precludes comparisons of the infectious dose and the pathogenic dose.

Human studies involving the vaccine polioviruses have been reviewed elsewhere (5). Studies in which infections resulted after ingesting from one to 20 tissue culture doses of vaccine poliovirus have been reported from the Wistar Institute (11,12,13); whereas others have reported infections only after $10^{3.5}$ or more tissue culture doses were ingested by large numbers of subjects. Obviously, there was no means of determining the pathogenic dose.

At least two pertinent studies of peroral infection by other enteroviruses have been done with experimental animals. Coxsackievirus B5 produced illness (which was the criterion of infection) when newborn mice ingested between 10^2 and 10^3 tissue culture doses (14). From the standpoint of relevance to our present topic, the most positive aspect of this study was that it was done with a virulent human enterovirus, and the most negative feature was that the mouse is not known to be the homologous host species for this virus.

My own group at the University of Wisconsin-Madison has done some yet-to-be-published work* in which porcine enteroviruses were administered perorally in water to young weanling pigs. Virulent strains of two different serotypes were used to challenge animals that were fed a "human" diet and maintained in individual isolators. Many infections, but no disease, resulted. With porcine enterovirus type 3 (Strain ECPO 6), infections were seen only in animals which received at least 1,000 plaque-forming units (pfu) of the virus, administered either as a single dose or given in aliquots on 4 successive days. Infections with type 7 (Strain O5I) occurred with doses as low as 350 pfu. The apparent cumulation of risk when a dose was subdivided and given over several days' time made it seem that there was no absolute minimum quantity of virus which must be ingested at once for infection to occur.

A tissue culture dose of an enterovirus, whether scored on the basis of plaque formation or of cytopathic effect, is equivalent to 10 to 1,000 virus particles. Unfortunately, none of the virologic studies discussed above included enumeration of virus particles, so there is no absolute basis on which to compare doses among studies or between viruses and other types of infectious agents. No viruses of groups other than the enteroviruses seem yet to have been used in peroral infectivity studies.

Protozoa

Human volunteers received cysts of *Endamoeba* (now *Entamoeba*) *coli* and of *Giardia lamblia* perorally in two studies published 25 years ago (15,16). One of eight volunteers who each received a single *Entamoeba* cyst became infected; the proportion of subjects infected by larger doses was greater, to a maximum of two out of two at a dose of 10^4 cysts. None of five volunteers who ingested a single *Giardia* cyst became infected; but all volunteers given doses from 10 to 10^6 were infected, except for 14 of a group of 20 at a dose of 25 cysts.

The biological or morphological unit of dose in these experiments was the cyst. When small numbers were given, cyst counts could be verified directly by microscopic inspection before administration. No illnesses resulted, even among those who got large numbers of *Giardia* cysts.

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MATHEMATICAL MODELING

All who deal with these kinds of problems aspire to a mathematical model that could be used both descriptively to summarize research results and prospectively in making risk assessments. An idea model would include at least three elements: a biological or morphological unit of the infectious agent, a target unit of the potential host organism, and a functional or probabilistic unit based on observed effect.

The biological or morphological unit of the infectious agent should be a single viral particle, bacterial cell, or protozoan cyst. These obviously differ greatly in the accuracy with which they can be counted. One could, if desired, ensure that every dose administered contained one protozoan cyst or that the average dose administered contained one bacterial cell, but it would be very difficult to estimate the number of particles in a small dose of virus with any accuracy. This difference exerts a significant effect upon the choice of a probability model that could be applied most efficiently to each of the three classes of infectious agents. There is also the problem that, to the degree that one can actually see and count morphologic units of the infectious agent, it is frequently impossible to determine whether these are viable, in the sense of being capable of carrying out their biological potential as infectious agents.

The target unit of the potential host organism presents problems of definition. The descriptive statistics of volunteer studies with young adult males sometimes necessitate a retrospective definition of susceptibility, as was mentioned previously. Prospective analyses require that the target unit be redefined to include all ages and states of health among persons in the population at risk. This definition cannot be done out of the context of the end effect that is being observed : persons who are not necessarily more susceptible to infection than the average may be significantly more likely than average to become ill if they are infected.

Finally, there is the problem of defining the functional or probabilistic unit of the effect that is being observed. As was mentioned previously, an infectious dose is one which produces infection, and infection may be defined in terms of prolonged shedding of the infectious agent or of development of humoral immunity against it. A pathogenic dose might be defined as the quantity of an infectious agent which produces specific symptoms of disease in the recipient. These definitions are apparently straightforward, but unfortunately there are data from specific groups in published human volunteer studies where the number of ill subjects exceeds the number infected, based on the criteria just stated.

Given all the problems in defining the variables in the system, it seems clear that no perfectly rigorous probability function for evaluating an infectious dose is attainable. For other reasons discussed previously, the calculation of a pathogenic dose apart from the infectious dose may well be a trivial exercise. It seems reasonable to conclude on the face of the matter that no useful mathematical model can be attained at this time. Nevertheless, applications of the Poisson formula and its derivative binomial distribution have succeeded remarkably in comparable situations in the past.

The distribution of infections is a quantal, all-or-none proposition, in spite of any problems there may be in defining the variables in the system. The Poisson formula provides a valid empiric means of analyzing data involving quantal variables (17) and serves as the basis for the multiple tube method of estimating coliform organisms in water and wastewater on the basis of most probable number. Applications of the Poisson distribution in quantitative virology have been well reviewed by Sobsey (18). In its simplest derivative, the Poisson formula can provide a point estimate of the peroral infectious dose by finding the negative Napierian logarithm of the fraction of those challenged with a given dose who do not become infected. Other derivatives of the formula allow one to calculate confidence intervals and to make projections of cumulated risk of infection after repeated small doses of an infectious agent. An alternative approach is to calculate the dilution in a geometric series which will cause infections in 50% of the recipients: there are convenient procedures for computing these 50% endpoints, but the results are of limited value in prospective applications.

RISK ASSESSMENT

Earlier I mentioned some worst-case assumptions that have often been made by others. I shall not attempt to deal with them individually here, but I think it is important to point out that a great many hypotheses have become common knowledge through frequent repetition, without ever really having been tested experimentally. This is undoubtedly the point at which to insert the standard plea for further research. I shall depart from expectations only to the extent of suggesting that first priority be given to studying the course of peroral (rather than aerosol) infections initiated by minimal doses of enteric agents and to characterizing the host factors that determine whether infection leads to disease.

No mathematical approach that is presently available will yield a valid assessment of the absolute probability that someone will be infected as a result of exposure to wastewater aerosols. Some estimates of the relative probability of infection appear possible; but it must also be remembered that disease is not guaranteed to result from infection, for the reasons discussed previously.

An important point to be made with respect to disease transmission via wastewater aerosols is that there is probably nothing about dissemination in aerosols that enhances the pathogenic potential of an infectious agent in wastewater. The infectious agents discussed here are largely produced in people's intestines and are generally unable to multiply in sewage. Therefore, the quantities of infectious agents that are present in the sewage and might be present in sewage aerosols will almost never exceed those that were present at the time the feces were voided. Many factors discussed earlier and by others at this symposium may result in reduction of pathogen levels, but there is no means by which most pathogens might increase.

Nevertheless, there will certainly be pathogenic infectious agents in wastewater aerosols. These are not known to be able to infect the lungs directly, so these agents represent a threat to human health principally in that they might be trapped in respiratory mucus and then swallowed or that they might settle on food or water and be swallowed. Either of these hypothetical modes of transmission is relatively indirect and is probably less efficient than contact in disseminating enteric agents. There is a dearth of experimental or epidemiologic evidence to suggest that the quantities of pathogens in wastewater aerosols are an imminent danger to those exposed to them. Prudence dictates that food and water should not be allowed to become contaminated by wastewater aerosols. On the other hand, my classes and other visitors frequently are exposed directly to aerosols from the activated sludge aeration units and other processes at the Madison Metropolitan Sewage Treatment Plant, and I would not continue to take groups there (nor would the plant continue to accept visitors) if there was any indication that illness was resulting.

CONCLUSIONS

Infectious agents of human intestinal origin, including bacteria, viruses, and probably parasite cysts, are present in wastewater aerosols and have a hypothetical potential to cause disease. Although a single biological unit (bacterial cell, viral particle, or protozoan cyst) of an agent may be capable of causing an infection, the single unit of most infectious agents almost never does produce infection, and substantial probabilities of infection are associated only with substantial numbers of biologic units. If infection does occur, the likelihood that disease will result from the infection depends first on the virulence of the infecting agent and second upon an array of host factors but probably very little upon the size of the dose by which infection was initiated. Sewage aerosols are probably a relatively inefficient means of transmitting enteric infections and are not uniquely likely to lead to disease in the public at risk. The significance of occupational risk can best be determined by prospective epidemiologic studies.

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DISCUSSION

MR. McCABE: I would like Dr. Phair to comment on Dr. Cliver's remarks about the respiratory pathway. Do you see it the same way?

DR. PHAIR: I think Dr. Cliver's remark is a fair generalization that the data on inhalation of enteropathogens as a significant mechanism of disease production are not very good.

DR. LUND: I would like to challenge that.

DR. PHAIR: Good.

DR. LUND: The highest production of virus is in the tissues of the upper respiratory tract, and if you go through the respiratory tract to the stomach you might bypass that area. For instance, you know in the days of the polio epidemics, people who had their tonsils removed had a higher risk of polio than others. I think that there might be such a thing as bypass and it might make a difference because of it.

DR. PHAIR: Just one thing that persuades me that that is not a major mechanism in natural infection is the finding, during the early polio vaccine trials, that minimal doses did not result in infection in the pharynx but rather in the intestine; quite large doses of the oral polio vaccine virus did infect the pharynx and then the intestine. But it looked as though the pharynx, in those studies, was less sensitive to virus than the intestine.

Suport for Dr. Lund's point has been found in at least one situation where there has been aerosolization of contaminated blood in dialysis units. There have been hepatitis B outbreaks associated with that sort of thing where a centrifuge, or something of that nature, broke. So it is not unheard of, but I think I agree with Dr. Cliver that it is not a major risk, except under unusual circumstances.

DR. GERBA: In terms of aerosol transmission, if I remember the literature correctly, individuals are susceptible to infection through aerosol transmission. I believe there were slides indicating that the infective dose was even lower with aerosol exposure. I don't think we should forget that any of these, especially viruses, can be transmitted by the respiratory route. In looking at aerosols we shouldn't exclude an organism just because it is an enteropathogen and say it can't be infective by aerosol transmission.

In terms of infectious dose, rather than the aerosol dose inhaled, aerosols settling out on surfaces can result in the transmission of disease by the aerosol route indirectly by touching contaminated surfaces. I think these things should be also taken into consideration when talking about aerosols.

DR. CLIVER: With regard to aerosols settling on surfaces, I did explicitly mention that. That is one of the possible routes by which these things might be transmitted. One of our concerns is to keep the stuff off the food.

I was not able to find anything indicating that *Shigella* did infect by the aerosol route more efficiently. I did find one article on *Salmonella typhimurium* which I didn't find persuasive because I know how many *Salmonella* spp. are in aerosols in poultry slaughter plants versus a true respiratory agent such as the ornithosis agent. We know of no outbreaks in poultry slaughter plants where the same workmen are exposed to these aerosols.

If they have the agent of ornithosia in their body they are going to get a pulmonary infection, but one does not see pulmonary salmonellosis except, perhaps, in severely debilitated people.

Responses to Wastewater Exposure with Reference to Endotoxin

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ABSTRACT

Workers at six sewage treatment plants in Sweden were the subjects, and workers at drinking water plants were controls for an investigation attempting to evaluate the presence of clinical symptoms among workers at conventional sewage treatment plants. Tests to determine the possible presence of a chronic infection or reaction caused by endotoxin exposure were applied, and the number of airborne gram-negative bacteria was calculated at various sites in the working places. Results showed that a high number of airborne gram-negative bacteria may be present at sewage treatment plants. Gastrointestinal tract symptoms were observed to be widespread, while fever and eye inflammation were less frequent. Numbers of white blood cells were not increased among nonsmoking subjects. A tendency to an increase of the IgG level was seen in subjects, as well as increased excretion of fibrinogen degradation products in urine. As there are high levels of gram-negative bacteria and bacterial endotoxins present in the sewage plant environment, it is suggested that symptoms are caused by exposure to airborne endotoxins.

A previous investigation has demonstrated that workers in a sewage treatment plant suffered from occasional episodes of chill, fever, and malaise (1,2). In that particular plant, the sewage sludge was heat-treated and transformed into a powder. When workers were exposed to the dust during handling of the mechanical equipment, acute symptoms of fever and eye inflammation appeared a few hours afterwards.

The present investigation was undertaken to evaluate the presence of clinical symptoms among workers in conventional sewage treatment plants. Based upon previous experience, tests to evaluate the possible presence of a chronic infection or a reaction due to endotoxin exposure were applied. The number of airborne gram-negative bacteria was determined at different working sites in the plants.

MATERIAL AND METHODS

The investigation was performed at six different sewage treatment plants in Sweden. The plants incorporated indoor as well as outdoor basins and other installations. Persons working at drinking water plants served as controls. An interview investigation was performed among the employees who were working in the plant at the time of the investigation and had been employed for at least 8 months. Practically all employees so selected participated in the investigation; only two refused.

The interview comprised general questions regarding length of employment, previous employments, smoking habits, and general health. Specific questions were posed concerning the presence of workplace-related eye inflammation, attacks of fever, and symptoms from the gastrointestinal tract or the skin. Blood samples were taken to determine the number of white blood cells and their distribution, the number of thrombocytes, and the amount of serum immunoglobulins. Fibrinogen degradation products (FDP) were determined in urine. With the ELISA technique, antibodies were determined against a pool of 10 common gram-negative *Escherichia coli* endotoxins or against endotoxins prepared from gram-negative bacterial strains isolated from sewage water.

The investigated group of employees is illustrated in Table 1. The total material comprised interviews from 262 persons and blood samples from 236. Forty-one persons were interviewed in the drinking water plants and 199 in the sewage treatment plants. The mean age and number of years employed were slightly higher among personnel at the drinking water plants. The proportion of smokers was 56% at the drinking water plants as compared to 44% at the sewage treatment plants.

Table 1. Workers Investigated in Drinking Water and Sewage Treatment Plants

	Water	Sewage
Interviewed N	41	199
Blood samples N	41	181
Mean age	47±13[a]	40±12
Years employed	13±11	7±7
% smokers	56	44

[a] ± indicates standard deviation

The number of airborne gram-negative rods was determined using a six-stage Andersen sampler with Drigalski agar selective for gram-negative rods. The number of bacterial colony forming units (cfu) was counted after incubating the agar plates at 30 or 35°C during 48 hours.

In certain of the measurements, parallel samples were taken. One sample was incubated as above, and the agar plates from the other sample were crushed in saline and serial dilutions were prepared of the slurry. The number of colonies was counted after incubation on Drigalski agar plates.

Different species of gram-negative bacteria were identified using the oxidation fermenting characteristics. Fermenting species were identified using the API system. Oxidative species were identified using biochemical and immunological techniques. No determinations of pathogens were made. The determinations of airborne bacteria were made at various working sites in the plants. Several determinations were made at each site, and the measurements were performed on two or more working days.

RESULTS

The determinations of airborne gram-negative bacteria in different parts of the sewage treatment plants demonstrated that the number of colony forming units ranged from 10 to more than $10^5/m^3$ of air. The highest values were reported near installations where aerosolization of the water took place, such as aerating basins and sludge pressing units. The number of colony forming units at sedimenting basins was low. In the drinking water plants, the number of bacteria was very low.

The gram-negative bacteria were mainly various strains of *Enterobacter, Klebsiella*, and *Pseudomonas* spp. The proportion of *E. coli* was less than 10% in most of the measurements, and in many of the samples *E. coli* could not be detected.

Comparisons between the number of viable organisms as detected by the Andersen sampler directly (cfu) and the number found after crushing the agar plates are reported in Table 2. The number of bacteria detected directly comprised less than 1% of the number found when the agar plates were crushed.

Table 2. Number of Viable Airborne Gram-Negative Rods by Direct Outgrowth on Andersen Sampler Agar Plates (cfu) and After Crushing and Suspending Slurry in Liquid (Dispersed)

cfu	2.7 ± (0.6)[a]
dispersed	464

[a] ± indicates standard deviation

The symptoms reported by the employees are seen in Table 3. The proportion of workers reporting fever and symptoms from the eye or the skin was slightly larger among the sewage treatment workers.

Table 3. Symptoms Reported by Workers in Drinking Water and Sewage Treatment Plants

	Subjective symptoms (%)	
	Water	Sewage
Employees N	41	199
fever	0	2
eye	2	6
skin	2	8
diarrhea	2	32

Concerning diarrhea or acute gastrointestinal symptoms, 32% of all the workers in the sewage treatment plants reported such symptoms, as compared to 2% in the drinking water plants. These symptoms were reported to occur particularly in connection with dirty working operations such as cleaning the bottom of basins or repairing pumps. They were more frequent when the employee returned to work after a prolonged absence, such as after holidays. The frequency of symptoms varied greatly—some reported that the symptoms were present a few times per year or less and others reported that they occurred almost every month.

The gastrointestinal symptoms developed a few hours after the particular exposure, lasted throughout the night, and usually disappeared the following morning. They were not accompanied by increases in fever or a headache.

Determinations of the number of white blood cells (Table 4) showed that among the employees at the drinking water plants, smokers had an increased number as compared to nonsmokers ($p < 0.1\%$). No difference was found between the nonsmokers in drinking water and sewage treatment plants. The number of white blood cells among smokers in sewage treatment plants was slightly lower than among smokers in drinking water plants ($p < 1\%$). No differences were noted with relation to the distribution of the various types of white blood cells.

Table 4. Number of White Blood Cells (x 10^3/ml) Among Workers in Drinking Water and Sewage Treatment Plants

	Nonsmokers	Smokers
Water	5.6±1.2[a]	8.9±2.7
Sewage	5.5±1.4	7.2±2.1

[a] ± indicates standard deviation

Regarding thrombocytes, no differences were found between nonsmokers and smokers or between workers in water and sewage plants.

Table 5 reports the amount of serum immunoglobulins among the investigated employees. Nonsmoking employees in sewage treatment plants had slightly higher values of IgG, IgM, and IgA as compared to nonsmokers in drinking water plants. The differences were, however, not statistically significant. No significant differences were found between the other groups of employees.

Table 5. Serum Immunoglobulins (mg/ml) Among Workers in Drinking Water and Sewage Treatment Plants

	Water		Sewage	
	Nonsmokers	Smokers	Nonsmokers	Smokers
IgG	11.4±3.1[a]	11.7±2.4	13.0±3.4	12.0±3.0
IgM	1.3±0.7	1.4±0.5	1.8±0.8	1.6±0.7
IgA	2.1±1.0	2.1±0.8	2.3±0.9	2.2±1.0

[a] ± indicates standard deviation

Table 6 reports the proportion of workers having an excretion of FDP in excess of 10 mg/l of urine. Among workers in drinking water plants, a larger extent of the smokers had increased values ($p < 0.1\%$). For nonsmokers, the extent of employees with an increased level of FDP was higher in the sewage treatment plants ($p < 0.1\%$).

Regarding antibodies to *E. coli* endotoxin or endotoxin from the gram-negative bacteria found in the sewage treatment plants, no differences were detected between serum antibody levels among workers in drinking water and sewage treatment plants.

Table 6. Percent of Workers in Drinking Water and Sewage Treatment Plants with Urine FDP Higher Than 10 mg/1

	Nonsmokers	Smokers
Water	6	22
Sewage	33	24

COMMENTS

The present investigation demonstrates that a large quantity of airborne gram-negative bacteria may be present in the sewage plant environment. The bacteria species were mainly of the kind normally present on vegetation. The same species are found in other industries where organic material is aerosolized, such as in cotton mills.

The data further demonstrate that determinations of the number of airborne viable organisms made using a particle impactor technique underestimate the true number of organisms by a factor of 10^2 to 10^3. This error is important if one wants to relate effects observed among the exposed workers with any parameter related to the number of bacteria such as the amount of toxins.

The reason for the discrepancy in bacterial numbers is that, with the Andersen sampler, a count is made of the number of particles on agar plates from which bacteria grow. Each particle can consist of a single bacterium (impacting mainly on the last plate in the sampler) or aggregates of bacteria (impacting mainly on the first plates). Thus, the number of colony forming units is not always related to the true number of airborne viable organisms in the sample of air studied.

The gram-negative bacteria present in the air of the sewage treatment plants contain capsular lipopolysaccharides—endotoxins. These may cause a variety of biological effects, even at low levels of exposure. No extensive determinations of the amount of bacterial endotoxins in the air of sewage treatment plants have been performed. Determinations of endotoxin levels in treated wastewater sometimes used for irrigation or cleaning purposes demonstrate levels of around 5 μg/ml. If a quantity equivalent to 1 ml were to be inhaled during a few hours, the endotoxin dose required to produce fever would be exceeded by at least five times.

Subjective symptoms and eye inflammation among workers exposed to products of sewage were reported already by Rammazzini (3).

Symptoms from the gastrointestinal tract were present among a high proportion of the workers in the sewage treatment plant. Such symptoms were not reported in the previous investigation on workers in the plant with sewage dust (1). Other symptoms such as fever and eye inflammation found in the sewage sludge drying plant were less frequent among workers investigated here.

A possible explanation for this difference in symptoms is related to the particle size distribution of the aerosols in the two types of sewage plants. In the plant with sewage dust, the particles were small, which allowed for penetration down into the alveolar region of the lungs. In the plants investigated here, the largest amount of particles was of a large size range, demonstrated by the fact that the majority of the particles impacted on the first agar plates in the Andersen sampler. This size favors deposition in the upper part of the respiratory tract with subsequent rapid clearance down into the gastrointestinal tract. Further studies are required to verify this hypothesis.

Gastrointestinal symptoms have also been found in a study on Danish sewer workers and in a small study among workers exposed to dust and sludge in a composting plant (4). In that plant, sewage and household garbage were milled together and subsequently stored until biological degradation occurred. Workers were exposed to large numbers of gram-negative bacteria mainly originating from the household garbage.

From a clinical point of view, the symptoms are different from those caused by infections of a viral or bacterial origin.

The number of white blood cells was increased among smokers as compared to nonsmokers. This is in accordance with findings from previous investigations. The sewage plant environment did not affect the number of white blood cells among nonsmokers. This indicates that, at least among the group observed, an important indicator of infection could not be demonstrated.

With relation to immunoglobulins, only a tendency to an increased IgG level was found among nonsmokers in sewage treatment plants as compared to nonsmokers in the drinking water plants. The previous investigation on workers exposed to sewage sludge dust demonstrated a significant increase in the IgG levels (2). The exposure was thus probably less among the group of workers investigated here.

The extent of workers having an increased excretion of FDP was influenced both by smoking and the sewage plant environment. An increased excretion of FDP indicates a general inflammatory response somewhere in the body. It is conceivable that a continuous injury to the lung due to inhaled tobacco smoke could be the reason for the increased amount of FDP excreted among smokers. The increase among nonsmoking workers in the sewage treatment plant also indicates an inflammatory response although the site of action cannot be determined.

In parallel to this it is worth noting that increases in the serum transaminase levels of workers in sewage plants have been observed in investigations from the United States and Sweden. This suggests that the liver may be involved in the inflammatory response after exposure in the sewage work environment. Systematic observations in relation to exact exposure conditions at work and other factors which influence transaminase levels such as alcohol consumption are underway to further elucidate the significance of these findings.

Epidemiological studies can never yield information on casual relationships between an observed biological phenomenon and one particular factor in a complex environment. Also, the exposure conditions for workers investigated here are not known in detail. Any suggestions as to the agent responsible for the observed symptoms among sewage plant workers must therefore remain hypothetical.

In view of the large amounts of gram-negative bacteria and bacteria endotoxins present in the sewage plant environment, it is suggested that the symptoms are caused by exposure to airborne endotoxins. The effects that appear are thus to be considered as toxic effects rather than a traditional infection.

Endotoxins are known to act as general mitogens which could explain the slight increase in IgG immunoglobulins found among sewage treatment workers (5). Exposure to endotoxins will also cause polymorphonuclear leukocytes to appear on epithelial surfaces such as the eye, as seen in sewage dust workers. In cotton mills where endotoxin is present in the air, a similar invasion of leukocytes takes place in the airways (6,7).

Exposure to large amounts of endotoxins could also explain the fever reactions among workers exposed to sewage dust and diarrhea among the workers in conventional plants. The liver detoxifies endotoxins, and it is feasible that increased burdens of this substance may be reflected by increased transaminase levels in the serum just as is the case after alcohol consumption, for example.

Large numbers of airborne gram-negative bacteria have also been demonstrated in cotton mills (8). The exposure conditions there differ from those in the sewage treatment plants in that the workers are constantly exposed to a high level over the whole week. Acute symptoms in the form of fever and malaise are, however, found among cotton mill workers when they initially start working in the mills (mill fever). This symptomatology corresponds to the effect seen among workers in the sewage dust plant.

In the present study, no investigation was made on the presence of precipitating serum antibodies against different microbiological agents present in the sewage treatment plant environment. However, no symptoms were reported which indicate that the effects would be an allergic type response. Antibody titers against *E. coli* endotoxin or endotoxin from the sewage plant gram-negative bacteria were not elevated among sewage treatment workers as compared to workers in the drinking water plant. This is in accordance with previous investigations which demonstrate that endotoxins are not very potent antigens and produce an immune response which is only of a relatively short duration.

The results from the present investigation cannot serve to judge the risk for the development of some type of chronic disease after working in a sewage water treatment plant for several years. As a matter of principle, however, an exposure at work which causes both acute clinical symptoms and systemic effects should be avoided, even if at present it cannot be demonstrated that chronic effects will eventually appear.

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DISCUSSION

DR. DEAN: Some of your data indicate that the sewage treatment plant is insulting the workers lungs in much the same way that smoking does. Is this an oversimplification?

DR. RYLANDER: I think at this stage I would be limited to saying that the body is insulted so that an inflamatory response occurs, but we do not at the present know if this really comes from the lungs. Otherwise you are correct and there is an insult.

DR. PHAIR: In the initial plant where they dried the sludge and there was dust, were there any respiratory symptoms at all in the workers similar to what you see in farmers exposed to farm dust?

DR. RYLANDER: Unfortunately, we were not able to measure those. The whole study in that plant was of an acute nature because they were going to close it down due to a malfunction of the equipment. We had to rush there and do the study in about a month's time and we never had the opportunity to come back again.

If I may throw out a hypothesis or two, if we were ever going to go back to the similar plant again, I would certainly look at respiratory function measurement and I would particularly pay attention to diffusion capacity measurements because there are studies from other environments where people have been exposed to endotoxins and gram-negative bacteria which clearly show that 4 to 12 hours after the exposure there is a decrease in diffusion capacity, which returns to normal about 24 hours later.

SPEAKER: Is it possible that working habits of sewage treatment plant workers in Sweden are different from the working habits of workers in the United States? For instance, many times I have visitors in my plant and they ask me where the workers are because, many times, they don't see people in my plant. We may have operators and maintenance people on duty but if you walked around my building you wouldn't see the people. Now, is that the case in Sweden or are those people exposed to the tanks and filters for greater periods of time?

DR. RYLANDER: That is a very important question. By and large, I would say that the working conditions do not differ. We see the same thing, that is, if you walk into a plant it could be entirely empty and you might not see anyone around to draw blood samples from. This explains some of the irregularities in the symptoms because, clearly, we are facing a situation where the workers are not reacting to the general environment like in the cotton mills but they are reacting toward specific situations in that working environment. One of our large goals in this project is to try to help manufacturers to define where these danger spots are. Adequate protection can then be taken by both sides.

Now, another problem relates to the finding of these symptoms and this very much depends on how you phrase your questionnaire. For example, you may go up to a worker and ask him (and this was an experience that we had in the sludge dust plant), "Do you ever have a disease?", and he may say no, or, "Are you ever absent from work because you have a medical problem of some kind?", and he may say no. Then we may say, "Do you have a fever in the afternoon?"; he says, "Yes, I have fever in the afternoon and then I go and take a cold shower."

MR. HAYMES: I agree that the smoke is a critical variable. First, I would like to ask you how you classify smokers and nonsmokers?

DR. RYLANDER: They were just classified as smokers and nonsmokers at that time. We felt that the material and the actual positive findings were too limited to actually allow us to go into a deeper analysis.

MR. HAYMES: If smoking turned out to be nonconfounding, given that the proportions of smokers in both of those groups were not significantly different, and if you pull the information in each group, water versus sewage, might you have gotten a significant type of finding? I would like to ask if you have tried it by pooling the analysis?

DR. RYLANDER: No, as a matter of fact, we haven't yet, but that is a very good suggestion and we could probably do that.

MR. JAKUBOWSKI: Have you considered that we all have large numbers of gram-negative organisms present in the intestines and, consequently, we have endotoxins. How can the infection of what I would assume would be a relatively small amount of additional endotoxins result in the production of the symptoms of diarrhea?

DR. RYLANDER: I don't think I am prepared to answer in immunological detail but, generally speaking, we do have a lot of gram-negatives and endotoxins. But those are mainly the *E. coli*. We have very little of the type of gram-negative bacteria that you find in the sewage plant environment, which is *Klebsiella* and *Enterobacter* which derive from the vegetation. Now, immunity against endotoxin is a crossover in a sense because, if you have immunity against *E. coli*, you have a certain immunity against others as well. It is certainly lower, or less, which means that once you exceed a certain dose you may develop symptoms. This is quite in contrary to the allergic response where you develop a response even to very minute doses of the antigen. In this case, I am suggesting that you need to dose a real group and then anyone who receives that dose will react. We have been trying to discuss with our ethics committee the possibility of running an experiment with people who would swallow the endotoxin to see if they get diarrhea, but the committee has not authorized it.

DR. LUE-HING: If I recall, you disputed current information about people who are working in enclosed areas. Could you give details?

DR. RYLANDER: A general answer would be that there is no difference. It is entirely dependent upon the ventilation system. Enclosed treatment plants generally had a very high quality in the air because they invested a lot on ventilation, whereas some of the outdoor plants had quite high levels. There was no correlation between symptoms and indoor or outdoor areas.

Health Effects of Nonmicrobiologic Contaminants

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ABSTRACT

The nonmicrobiologic contaminants of wastewater aerosol have received scant attention in comparison to the rather intensive efforts made to characterize airborne microbiologic hazards. While this dichotomy is normal in view of public concern over potential infectious disease transmission, appreciation is slowly being gained that toxic gases and myriad chemicals, both organic and inorganic, may also pose a significant hazard to wastewater treatment workers and potentially to the general public in surrounding areas. A number of acute disease episodes have already been reported as affecting occupationally-exposed treatment plant personnel. Of more concern is the potential for chronic long-term effects from repeated low-level exposure—exposure which may also have conceivable impacts beyond plant confines. This paper discusses the known toxic effects of substances which have been identified in various wastewaters or those which may be formed by the interaction of chemical pollutants. Emphasis is placed on the respiratory route of entry and upon the effects of systemic absorption. This paper seeks to put the general environmental exposure hazard into a rational perspective based upon occupational experiences.

I am sure it is obvious to all that my discussion cannot begin to cover every conceivable nonbiologic substance contained in wastewaters which is possibly hazardous to man via the respiratory route. The occupational hazards of sewer workers have long been recognized. Infectious hazards aside, men working in sewer systems are commonly liable to accidents causing physical injury, to drowning, poisoning, and to gassing accidents, including the explosion of air containing CH_4 or gasoline vapor. Dr. Donald Hunter, the late Dean of English Occupation Medicine, has aptly described sewer workers as "generally of small build, cheery disposition, and almost fearless. What attracts them to the job is the certainty of continued employment" (1). Obviously, persons working at wastewater treatment plants are subject to substantially the same risks as those actually working in the connector and interceptor sewers. The fact (or possibility) that some of these same risks are faced by the general population living in the vicinity of wastewater treatment plants is far more nebulous and has only come under close study in recent years.

I will try to confine my remarks to the pathophysiologic events associated with identified hazards and real world problems which might, at least on rare occasion, be found in the waste treatment plant environment. I will not try to be encyclopedic or even reasonably complete in my compendium—for more likely than not the next hazardous episode achieving notoriety will be due to some previously unrecognized contaminant.

Since we are concerned with substances entering the body via the respiratory tract, I would like to take a few minutes to review and summarize our anatomic and physiologic knowledge of this vital system. The physiologist defines two types of respiration. The first is external respiration, i.e., the act of or mechanisms of breathing. The second, or internal respiration, refers to cellular respiration. This encompasses the utilization of O_2 at the cellular level with the production of energy, growth, and the synthesis of cellular products such as enzymes and hormones. In carrying out the functions, many waste metabolites are formed, for example CO_2, which are removed by the lungs. Nongaseous wastes are, of course, primarily removed by the liver or kidney.

Blood serves as the medium of conveyance between the lungs and the tissues. Whole blood is about 45% comprised of red blood cells which contain hemoglobin. Each molecule of hemoglobin can combine with two atoms of oxygen and carry them to the tissues. The noncellular component of blood, the serum, transports waste CO_2 as HCO_3 to the lung where the enzyme carbonic dehydrogenase converts the ion to water and gaseous CO_2.

The nose is the normal entry point for the air we respire and also serves as the organ for the special sense of smell. The nose serves as a filter and also warms and moistens air. Large particulates are trapped here, and highly soluble compounds may dissolve in the mucous coating and result in irritation.

The nose empties into the throat or pharynx, the muscular organ common to both the respiratory and alimentary tracts. Toward the front of the lower part of the pharynx is the larynx, through which air passes into the trachea. The entry to the larynx is guarded by the epiglottis, a valve, which prevents the entry of food or drink into the lower respiratory tract. The trachea or windpipe is about 5 in long and is made of semirigid rings of cartilage and smooth muscle. At its lower end it divides into two main bronchi, each of which enters the substance of the lung before bifurcating repeatedly into smaller and smaller divisions. There are 13 reduction divisions in all, and when inverted, the entire bronchial structure resembles a tree with the trachea serving as the trunk. The smallest divisions are called bronchioles and terminate into alveolar ducts which are lined with small sac-like structures known as alveoli. Each duct and associated alveoli resembles a bunch of grapes. This terminal structure consists of only a single layer of squamous epithelial cells since supporting structures, cartilage, and muscle, are lost after the first five or six divisions. Each alveolus is surrounded by a capillary network which is itself only one endothelial cell thick. It is between these two cell layers that actual gas exchange occurs. Finally, surrounding the lung and maintaining its general structure is a shiny membrane known as the pleura. The lungs are enclosed in the thoracic cavity or chest cage, which is made up of the ribs and associated muscles. The inner surface of the chest cage is also lined with pleura, and normally no space exists between the surfaces of the lung and thorax; the opposing pleurae are held together by surface tension.

The normal adult usually breathes about 16 to 18 times/min, and each breath carries about one-half liter of air. However, only that air reaching the alveolar ducts and alveoli, approximately 360 ml, is available for gaseous exchange; that air filling the trachea, larynx, nose, etc. comprising dead space. Toxic materials in the air may enter the respiratory system as gases, vapors, fogs, fumes, or particulates and cause damage. Adverse effects result from one of a number of potential mechanisms (Table 1), and it should be remembered that these types of effects are not mutually exclusive; for example, an agent may act both as an irritant and also produce systemic intoxication due to absorption.

The simple asphyxiants prevent adequate oxygen from reaching the lungs. They are essentially inert in the physiologic sense but can cause death when men are exposed to them in closed spaces. Most of them are heavier than air and accumulate, displacing the lighter oxygen. Especially dangerous in regard to these agents are tanks, tank cars, ship holds, fermentation vats, old mines, and the like. Deep wells in wastewater treatment plants may pose a similar hazard. The simple asphyxiants are important because they are common, and they can overcome men quickly; artificial respiration is lifesaving if begun immediately. The symptoms of oxygen lack are given in Table 2.

Chemical asphyxiators act even in the presence of oxygen by interfering with oxygen transported by the red cells (CO) or by poisoning the enzyme system required for cellular respiration (cyanide).

To a great extent, respiratory tract irritation depends upon the solubility of the material. Highly soluble gases and substances dissolve in the mucus membrane lining of the nose and throat resulting in upper respiratory tract irritation. In higher concentrations, this may be noticed almost

Table 1. Types of Respiratory Responses

Mechanism	Example(s)
Asphyxia:	
Simple	Methane, N_2, He_2, H_2, CO_2
Chemical	Cyanide, CO, H_2S
Irritation	NH_3, Cl_2, phosgene, SO_2, NO_2
Absorption:	
Systemic toxins	Cd, benzene, Hg, trinitrotoluene
Anesthetics	Chlorinated hydrocarbons, xylene, trichloroethylene
Deposition:	
Pneumoconioses	Silica, coal dust, asbestos
Benign pneumoconioses	Sn, Ca, Ba
Allergy (immunologic):	
Immediate (asthma)	Wood and grain dusts, enzymes, toluene diisocyanate, aminoethylethanolamine
Hypersensitivity pneumonitis	Fungal spores growing in hay, cork, bark, wood pulp, compost, etc.; protein materials
Pharmacologic (nonimmunologic)	Byssinosis, flax
Infection	Psittacosis, anthrax, viruses?
Neoplasia:	
Lung	Bis-2-chloromethyl ether, Ni, As
Other sites	Vinyl chloride, benzidine

Table 2. Symptoms of Oxygen Deprivation

Oxygen Concentration (%)	System(s)
21	Normal
12–14	Increased respiration and pulse, decreased coordination
10–12	Giddiness, cyanosis
8–10	Death in 8 min
4	Coma in 40 sec, convulsions, respiratory paralysis, death

immediately. Upper tract irritation is almost always accompanied by eye irritation as the materials dissolve in the fluid coating the conjunctival membrane of the eye. These are among the most common complaints in the occupational setting. Less soluble gases result in irritation of the deeper structures of the lungs. For example, phosgene may cause no symptoms for several hours after exposure but may then be manifest by severe irritation as the damaged alveoli permit an influx of fluid from the vascular system. This is termed pulmonary edema and is quite serious. A second effect from this class of agents is chemical pneumonia resulting from the infiltration of cellular elements, particularly white blood cells, and fluid into the alveoli. Very poorly soluble substances may pass directly into the blood stream and result in systemic poisoning or anesthetic effects if the agent can cause central nervous system depression. Thus, insoluble gases have little or no effect on the organs of respiration but may produce severe systemic toxicity. Several of the most important of these gases are described in Table 3. It is worth noting that several of these are metalloid hydrides.

Let us turn our attention briefly to the potential problem of allergy. Allergy has been defined as a modified response to a substance and usually implies an adverse response as opposed to a protective or beneficial one. The development of respiratory allergy depends to a large extent upon the presence of certain poorly understood personal factors which appear to be genetically determined. Thus, for any given exposure only some persons will become allergic to the substance. About 15% of our population, called atopics, commonly develop allergic respiratory sensitivities. This tendency usually manifests itself early in life, often in infancy, and usually as hay fever and/or asthma. It is true, however, that some persons may not manifest sensitivities until later in life. It is also true that predisposed persons will vary widely in the concentration of allergen and number of exposures required to induce allergy; some persons require years of exposure and others only a single exposure. However, the critical point is that once allergic induction has occurred, i.e., once a person has become sensitive to a substance, future exposures to only extremely minute amounts are sufficient to provoke allergic symptoms. Thus, the allergic response is largely dose independent. Exposures sufficient to cause symptoms are usually far less than those required originally to induce the allergic state. Thus inhalant allergy is a serious matter which often requires a change in occupation when the substance is a chemical or even a move to another area of the country when the offending materials are botanic in origin.

Unlike allergic contact dermatitis, where the allergen is usually a small and simple molecule, most inhalant allergens are large and complex proteinaceous substances, often pollens, spores, molds, or organic dusts, i.e., materials of natural origin. Since enormous quantities of bacterial and mycotic organisms may grow in drying sludge, there may be some potential hazard to workers and conceivably to other persons in the neighborhood. However, these microorganisms are by no means exclusively associated with sludge and are found widely in our general environment. Therefore, it is not an easy matter to incriminate dried sludge or compost as causative in the sporadic occurrence of such a common disease as asthma. While respiratory allergy is usually due to organic dusts, it is conceivable that aerosolized liquids containing appropriate allergens might result in sporadic allergic problems, although this seems quite rare.

Four groups of contaminants are reported to occur commonly in typical sewer off-gas: group I, CO_2; group II, solvents and other volatile oils, including chlorinated hydrocarbons; group III, H_2S; and group IV, sulfides, alkylamines, and aldehydes (2). The concentration of CO_2 commonly runs 2,000 to 12,000 ppm; the solvents about 500 ppm; H_2S up to 15 ppm; and the group IV compounds 0.01 to 0.05 ppm. CH_4 has been reported at levels of 41 to 460 ppm in a typical modern wastewater treatment plant (3). The level of all these pollutants shows great day-today and even hour-to-hour variation in concentrations.

CO_2 is a simple asphyxiant, and levels of 15,000 ppm begin to result in some physiological changes such as increased respiration. A concentration of 10% (100,000 ppm) can result in sufficient oxygen deficiency to produce unconsciousness and death. The current federal standard is 5,000 ppm. CO_2 is a heavy gas which accumulates at low levels and displaces air. Generally, adequate ventilation is all that is required to sufficiently protect workers.

Both individuals and industries contribute unintentionally (or otherwise) gasoline, fuel oils, spent motor oils, and other lubricants to our

Table 3. Important Highly Toxic, Relatively Insoluble Gases

Agent	Formula	Source(s)	Effect(s)
Phosphine	PH_3	Phosphide insecticides Phosphorus explosives	Odor of decaying fish CNS depression Pulmonary edema Cardiac arrest
Stibine	SbH_3	Acids acting on antimony	Hemolytic anemia
Carbon disulfide	CS_2	Rayon, cellophane manufacture	CNS depression Psychosis Atherosclerosis
Nickel carbonyl	$Ni(CO)_4$	Nickel refining	Pulmonary edema Hemorrhage
Arsine	AsH_3	Metal smelting and refining	Hemolytic anemia Jaundice Pulmonary edema

sewers. These hydrocarbons float and are relatively immiscible. Explosion is an obvious hazard from these volatiles. Gasoline is irritating to the skin, eyes, and mucous membranes, and the vapors may act as a central nervous system depressant, with very high concentrations causing coma and respiratory failure. Hemorrhage of the pancreas, fatty degeneration of the liver, and degeneration of the kidneys may also occur (4). The composition of gasoline is so varied that a single federal standard is not possible; n-heptane and n-hexane are usually present as major ingredients, however. The latter compound has also resulted in peripheral neuropathy as an effect of chronic exposure. The federal standard for both compounds is 500 ppm (5). The 1978 American Conference of Governmental Industrial Hygienists (ACGIH) lists a threshold limit value (TLV) of 400 ppm for n-heptane and 100 ppm for n-hexane as a result of the peripheral neuropathy that has been observed (6). The aromatic hydrocarbon content is considerably more important from a health standpoint than are the aliphatics. Benzene may be present in gasoline in concentrations of up to several percent and is also widely used as an industrial solvent. Acute benzene exposures, as with most hydrocarbons, result in central nervous system depression. Death may occur from large acute exposures as the result of ventricular fibrillation. Chronic exposures are also well-documented, and benzene is a myelotoxic agent, i.e., it affects the formation of various blood cells in the bone marrow. Blood counts may decrease dramatically and fatal aplastic anemia ensue. It is now generally accepted that benzene is leukemogenic, and the evidence that acute myelogenous leukemia may result is now quite convincing. Recent work has also demonstrated an increased incidence of chromosomal aberrations in association with benzene myelotoxicity (7). These changes may last for years following cessation of exposure and may give rise to the leukemic clones which cause the resulting leukemia. Organolead and antiknock compounds may also represent serious hazards. Tetraethyl and tetramethyl leads are used singly or together as antiknock compounds in gasoline. Both alkyl leads may rapidly penetrate the skin without local reaction and/or may enter the body via inhalation of vapor. The effect may be lead encephalopathy with hallucinations, delusions, convulsions, and toxic psychosis. An early fatal outcome may result. Recovery may be very slow but is usually complete. The federal standard for tetraethyl lead is 0.075 mg Pb/m^3 and 0.070 mg Pb/m^3 for the methyl compound (5).

Cd, Pb, and Hg levels in blood, feces, hair, and urine have been examined in persons living in proximity to Chicago's John Egan wastewater treatment plant (8). Preexposure levels were compared to those found after the plant was fully operational. No statistically significant increases in metal content were seen in any of the fluids or tissues analyzed. Surprisingly, some metal values significantly declined during the exposure period; i.e., fecal Cd and Pb, hair Cd and Hg, urine Pb and Hg, and blood Hg. Five of these decreases were significant at the $p < 0.001$ level. While there is no apparent explanation for these declines, other than perhaps some differences in sample storage times or analysis by different personnel, these results are, to say the least, reassuring, and the data gives absolutely no support to any adverse sewage treatment plant effect. This was anticipated since drinking water, food, and tobacco represent the major pathways of exposure; even in heavily industrialized areas the general public will have only relatively trifling exposure via air. Thus, shifts in human metal content are far more likely to be impacted by changes in dietary or tobacco habits or even seasonal variations in water drinking.

H_2S, or sewer gas, is a serious risk to life whenever circumstances permit high concentrations to develop. This hydride may occur whenever acidic solutions contact sulfides or from the anaerobic putrefaction of sulfur-containing proteins. It is also found near volcanoes and in lead, gypsum, coal, and sulfur mines where it is called "stinkdamp." Natural gas from some oil fields, especially those associated with high sulfur content crudes, may contain dangerously high concentrations. In addition, it is also found along with CS_2 in emissions from the viscose process used to manufacture rayon and cellophane. Being heavier than air, the gas tends to accumulate in low pockets, mines, wells, etc. where there is inadequate ventilation. At high concentrations, its toxic action is virtually as rapid as any agent known; affected individuals drop and die almost instantaneously. It is a leading cause of death in the workplace. The action is comparable to cyanide with immediate respiratory paralysis. Both compounds are potent inhibitors of cytochrome oxidase (9). Typically, would-be rescuers are sequentially overcome trying to save already unconscious fellow workers. In the past decade, a number of such multiple tragedies have been reported: seven worker deaths in a Chicago tannery (9), six in a Maine tannery (9), 11 in the holds of small fishing vessels (10), six in a rendering plant in Ohio (11), and farm workers overcome following the agitation of liquid manure systems (12). Sulfmethemoglobin is formed from the normally small amount of methemoglobin present in the blood, but this is not important pathologically in acute poisoning cases. In fact, agents enhancing methemoglobin formation such as $NaNO_2$ are protective in H_2S poisoning, since the sulfmethemoglobin complex is tolerated and spontaneously decays with a 2-hour half-life to oxyhemoglobin and an unknown sulfur compound.

Low doses are irritant and cause symptoms appropriate to upper respiratory tract irritation, i.e., photophobia, sneezing, tearing, and soreness of the mouth and throat. Exposures to 1,000 ppm may be rapidly fatal, and some men may develop serious symptoms after prolonged exposure to less than 100 ppm. Chemical conjunctivitis has frequently been reported at levels below 20 ppm and the ACGIH recommends a TLV of 10 ppm (13). The Federal Occupational Safety and Health Administration sets 20 ppm as the acceptable ceiling concentration but has not established an 8-hour time-weighted average. The lower limit for the odor threshold is 0.02 to 0.03 ppm. Above 30 ppm the characteristic rotten-egg odor is perceived as sweet, and above 100 ppm the sense of smell is rapidly abolished. Olfactory fatigue also occurs with prolonged exposure to lower levels, and the odor cannot be relied upon as a warning, especially of high concentration. H_2S is not an accumulative poison; and overcome individuals, once revived by resuscitative measures, have no late sequelae. Hence, prompt recognition may be lifesaving. Air-supplied respirators should be available wherever there is any potential for H_2S accumulation. In this way, the multiple casualties so commonly reported for this agent may be avoided.

Persons exposed to water containing pollutants may respire volatile components contained in the polluted solution. This is an area that has received scant attention to date, but it is evident that substantial exposures may ensue; the Louisville episode (14) is a prime example. It is possible to calculate theoretical air concentrations from the physical, chemical, and thermodynamic properties in question (15). These calculations are based on the gas laws and apply to stable systems under equilibrium conditions. Unfortunately, ideal equilibrium conditions do not exist in the real world. Nonetheless, it is of some interest to compare the idealized results with some actual measurements we recently made in a plant whose well had become contaminated with benzene from a nearby chemical landfill (Table 4).

Table 4. Comparison of an Estimated Benzene Concentration with Measurements Made in an Actual Exposure Situation

Location/sample	Water concentration (ppm)	Vapor concentration (mg/m³)
Hypothetical estimation (15)	10.0	0.966
Plant tap water	9.1	—
Plant shower room with water running	—	23.4
Near plant wash basin with tap running	—	1.2
General workroom air during normal operations	—	0.1

Using the commonly applied figure of 10 m³ for the ventilation rate during a normal workday and assuming that all the benzene inhaled is absorbed by the lungs, one can calculate an approximate daily dose of 1 to 10 mg attributable to air alone. To this an unknown amount from percutaneous absorption should be added.

It is obvious from the Table that the actual conditions differed markedly from the equilibrium situation, as might be anticipated. The data also points out that under some special situations, especially where the water is in agitation or undergoing aerosolization, the levels may considerably exceed those anticipated by equilibrium conditions. Nonetheless, the expected values are reasonably close to the observed, at least in comparison to many orders of uncertainty that we commonly have to work with in toxicology.

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DISCUSSION

DR. LUCAS: I have a note from Dr. Dean. A minor point, but a very valid one, where he is pointing out that a small molecule, SO_2, gave him the asthma. SO_2 is an irritant, and any good irritant will predispose to an asthmatic reaction. So, you are not allergic to SO_2, but it sure can produce asthma.

DR. GERBA: Have you ever considered interaction between irritants and infectious disease? I know that some types of pesticides seem to enhance susceptibility of certain types of viral infections in animals, and tissue cultures had demonstrated that pesticides can enhance the susceptibility to infection by certain RNA viruses. Have you ever considered this in evaluating the effects of cotton or other organic substances?

DR. LUCAS: Yes, in a sense. We have had, for a number of years, a streptococcus that is sufficient to produce a fatal illness. Mice get a fatal pneumonia from this particular strain. We also expose similar groups to certain airborne pollutants, and regardless of what the pollutant is, if it is an irritant like any of the oxides of nitrogen, we do see a definite increase in mortality using that particular animal model. However, I don't think we have done any work with tissue culture.

DR. GERBA: In other words, you are saying it lowers the infectious dose?

DR. LUCAS: In essence, I think one could draw that conclusion. This would enhance the susceptibility to a severe illness.

MR. WITHAM: Are you implying that the increase in amounts of benzene that you found are due to the aerosols and thus increased surface area?

DR. LUCAS: I am implying only that it comes from the water. There is no benzene whatsoever used in this plant. We know the water in the plant contains benzene. I thought it was simply an interesting comparison against some theoretical calculations under ideal equilibrium conditions. I use benzene, really, just as an example. It happens to be a real world example and one where we actually have some data and where someone has gone through the trouble of running it through a rather complicated mathematical formula to get some theoretical values for us. There aren't many substances for which this has been done. I think this is an area that needs substantial enlargement.

MR. WITHAM: In other words, the amount of benzene we have in the air is all available from what is in the water. It seems like a tremendous amount.

DR. DEAN: I might add a little bit to that. Benzene is really highly soluble in water. You think of it as a hydrocarbon insoluble in water but it is quite soluble, about 700 mg/1. If you heat water you will boil off a lot of the benzene. Was your theoretical calculation based on room temperature or hot water?

DR. LUCAS: Under standard conditions.

DR. DEAN: Okay, but this is hot water.

DR. LUCAS: But in the shower room it was hot water.

DR. DEAN: That would account for the difference very easily.

DR. LUCAS: But, unfortunately, most people don't take cold showers.

Epidemiologic Approach to Disease Assessment

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ABSTRACT

Epidemiologic studies are the primary means of assessing potential adverse health effects on populations exposed to wastewater aerosols. The investigations presented at this symposium use many of the classic methods of infectious disease epidemiology to test associations between health status and wastewater exposure. The interpretation of the results of these studies requires the understanding of some of the central epidemiologic issues common to many of the investigations. These issues include the following parameters: exposure assessment, health status measurement, the determination of associations between exposure and outcome, and the effects of confounding and bias.

Methods of exposure assessment have focused primarily on air monitoring techniques, but the actual dose of pathogenic organisms received by the population at risk is dependent on many host, environmental, and infectious agent factors which are difficult to quantify. Variables measured to detect adverse health effects include parameters ranging from serum antibody changes to illness diaries, each having certain strengths and shortcomings. The determination of associations between wastewater exposures and health outcomes has been made by analyzing dose-response relationships, control group comparisons, and trends over time. Potential sources of confounding and bias must be considered in relation to each epidemiologic approach. Study population sample size availability often is a limiting factor in the design and conduct of epidemiologic studies.

The primary objective of this paper is to introduce principles that are relevant to the design, performance, and analysis of epidemiological studies conducted to test the hypothesis that exposure to wastewater aerosols is associated with human disease. Because investigations carried out to test this hypothesis utilize such a variety of designs and methodologies and, therefore, include epidemiologic issues of a comprehensive nature, it will be necessary to focus on those issues which are most critical to the assessment of the health studies to be presented at this symposium. I will introduce epidemiologic concerns in relation to the following areas: study design, disease ascertainment, exposure assessment, major sources of confounding and bias, sample size, and criteria for establishing causation. The purpose is to review some principles that should be addressed in the performance of sound studies so that the research presented in the remainder of the session can be better evaluated from an epidemiologic perspective. Because a rather wide range of topics is to be covered, there is a resulting lack of depth of discussion in many areas.

Study design is the first area of discussion. The majority of the wastewater aerosol studies utilize a prospective cohort design. One definition of a cohort is a group of individuals sharing a common experience, and in this case the experience is presumed exposure to sewage aerosols. The prospective approach implies that the cohort is followed forward in time while disease status is determined. This design is unquestionably the most appropriate one for the majority of investigations where acute infectious diseases are the health outcome of major concern. Because most infectious diseases are self-limited and of short duration, their prevalence at any one point in time in the general population is low. Even relatively common illnesses such as respiratory infections may occur on the average less than one to several days per year in each person. Therefore, in order to accumulate sufficient illness experience to be able to compare two populations, it is necessary to follow the study groups for an adequate period of time, which may be months or years, depending upon the sample size chosen. By ascertaining illness that develops in the groups, incidence rates for specific diseases and symptoms can be determined. The incidence of disease is the number of new cases occurring in a population at risk per time period. One of the greatest advantages of the prospective cohort designs is that illness incidence rates can be most accurately estimated with this approach.

Alternative designs utilize a retrospective approach to measure illness occurrence. This implies either using available medical records, or using a questionnaire to ask individuals about illness during some recent past time period. In certain instances where usable records such as school absenteeism are available, a retrospective design can be more efficient. Unfortunately, very few records exist on population groups that are complete enough to be of value in measuring infectious diseases, which means that a questionnaire approach is usually necessary. This entails the major drawback of inaccurate subject recall. It is very difficult to obtain accurate histories of short-duration symptoms and diseases. In comparison, the advantage of a prospective study is the potentially complete enumeration of illnesses and calculation of incidence rates. Also, the control for confounding variables may be better with the prospective approach. Disadvantages are the necessity to follow individuals for a long time period, the difficult logistics, participant drop out, and expense.

Regardless of the design chosen, all studies must utilize some method of ascertaining and quantifying ill health in the population. Common sources of morbidity data are shown in Table 1. Reportable diseases refer to those specific diseases that are recorded by state health departments by requirement. Epidemic reports result from investigations of

Table 1. Sources of Morbidity Data

Reportable diseases
Epidemic reports
Hospital, clinic, and physician data
Public health laboratory reports
School absenteeism
Population-based health surveys

sporadic outbreaks of disease. Hospital clinic and physician data are self-explanatory. Population-based health surveys refer to systematic morbidity studies, such as the National Health Survey.

Because of serious limitations usually related to incomplete disease ascertainment, these sources of data are generally not useful for conducting investigations of hypotheses that small segments of the population are at an increased risk of illness because of some exposure. The exception is the category entitled population-based health surveys; most of the wastewater aerosol investigations utilize some form of these surveys in order to obtain health status of the study population.

These surveys are performed by selecting a representative sample of the population, soliciting volunteers for participation, and proceeding to collect the relevant demographic and medical data. Various methods are utilized to obtain information about health status. In the prospective cohort survey, an individual illness diary is frequently utilized to record disease occurrence. This is usually done by having a member of each household record for each day the occurrence of symptoms and illness in every family member. While this appears straightforward, there are important aspects of the recording process that can impact the results obtained. First, it is necessary to define illness in such a manner that all participants have the same general perception of illnesses to be reported. This may vary considerably according to the instructions given or amount of contact with the research team. The mechanism of reporting can influence the accuracy and completeness of reporting. Are diaries merely collected periodically, or does someone regularly contact each household to review the diary, answer questions, etc.? A more frequent reporting and personal contact schedule would generally be expected to yield more accurate results. Interviewer training is crucial because the instructions, guidance, and enthusiasm given by interviewers could certainly influence the diligence with which diaries were kept. Finally, symptoms and diseases must be abstracted from diary records in a systematic, standardized manner.

Administering a questionnaire presents some different potential problems. A sound design is essential with adequate pretesting. The reporting interval refers to the retrospective time period of recall of illnesses. It is important to know the length of time back to which people were asked to recall illness because, as this time period increases, accuracy decreases. Again, interviewer standardization and training is essential to assure comparability of data.

An alternate method of infectious disease ascertainment is through the use of serology. This technique involves the collection of a blood sample, separation of the serum, and determination of the amount of circulating antibodies to those specific microorganisms. A second sample is collected at a later time, usually weeks or months later, and the antibody levels are again measured. A fourfold rise in an antibody titer is generally considered indicative of infection with that specific agent. Advantages of serological testing are listed in Table 2. Probably the greatest advantage is that it is an objective measure of infection, a laboratory procedure determined and applied in a standard manner. This is in contrast to self-reporting and questionnaire data. Second, this technique identifies specific pathogens. Potentially, the particular agent can

Table 2. Advantages of Serologic Methods

Objective measure of infection
Identifies specific pathogen
Information on both clinical and subclinical infections
Integrates past infectious experience
Excellent measure of incidence

then also be identified in environmental samples such as wastewater aerosols. Serology provides information on both clinical and subclinical infections. Because many infectious agents produce infections without any clinical symptoms in a large proportion of persons affected, a more complete picture of the population's experience with that microbial agent can be gained from serological surveys. Another advantage of serology is the persistence of antibody levels for long periods of time. This enables information to be gained about past infections. Finally, the documentation of antibody-level increases is an excellent indication of the incidence of an infection, as rates of occurrence of new cases can be readily calculated.

In spite of these advantages, there are substantial limitations to the use of serology (Table 3). First, it is suitable only for selected agents and is not useful for all pathogens of interest in sewage aerosols. Second, it is necessary to test specifically for the correct agent in the group studied. It is not a broad screen for infections but is utilized to identify particular viruses and bacteria. Third, a pre- and post-infection serum specimen is needed, necessitating blood-drawing at least twice from each subject. The expense can be quite high when testing for multiple agents. Finally, although documentation of an infection may be termed an adverse health effect, it is not as clear, if very few or no symptoms are present, how much of a hazard this represents to the exposed individuals. It can be argued that development of antibodies without any perceptible clinical disease is not a health threat. Overall, serologic epidemiology appears to offer many distinct advantages for studying infectious diseases in populations. Increased use of this method in future research may be expected.

In addition to evaluating the health status of individuals studied, it is essential to collect certain social, personal, and demographic information (Table 4). The primary reasons for obtaining this information are to further categorize healthy and ill individuals and to ensure that no confounding variable has been introduced. A confounder is a factor that is related to both the disease outcome and the exposure and is differentially distributed in the control and exposed populations. The simplest example of a potentially confounding factor in these wastewater studies is age distribution. We know that children experience higher rates of most acute infectious disease than adults. Suppose that there are twice as many subjects under age 12 in the exposed group than the unexposed controls. Then it is obvious that a greater disease incidence in the exposed group could result from this age difference alone, and age would be termed a confounding variable. Four major sociodemographic variables are age, sex, race, and social class. All of these, particularly age and social class, are related to illness incidence and therefore need to be similarly distributed in the various exposure categories. If they are not similarly distributed, there are methods of dealing with the problem through stratification, adjustment, or multivariate analysis. Unfortunately, it is commonly the case that, even when these variables are measured in surveys, they are subsequently ignored during the analysis of the data. Particular attention should be paid to the treatment of potentially confounding variables in the assessment of the validity of findings of these epidemiologic studies.

Bias is the systematic introduction of error into a study. The first source in Table 5, sampling, refers to selection of the study population, and not purely to statistical considerations. Ideally, the study groups should be comparable in regard to all important factors except the risk factor under consideration. The samples selected should also be representative of the parent population. A randomizing technique is often used to generate samples, but this does not ensure representative unbiased samples. If a sampling scheme is used where selection may be a problem, then the samples should certainly be examined for the distribution of all important variables to determine if the exposed and control groups are alike. Closely related to sampling is the issue of nonparticipation or nonresponse. When the response rate is not high, that is, when it is below 80 to 90% of those selected, there is always the concern that the respondents differed in some important characteristic from the nonrespondents. Thus, the nonrespondents should be examined whenever possible to determine their similarity or differences from the respondents. Observer variation reflects the influence that the researchers have

Table 3. Limitations of Serology

Suitable only for selected agents
Need to test for correct agent
Need to test at correct time periods
Expense, logistics, inconvenience
Risk assessment interpretations

Table 4. Sociodemographic and Personal Variables

Age	School attended
Sex	Occupation
Race/ethnicity	Length of residence
Social class	Medical status
Income	Immunizations
Education	Travel

Table 5. Major Sources of Bias

Sampling
Nonparticipation or nonresponse
Observer variation
Errors of response

on the responses of the study groups. This has been referred to previously as interviewer effects. Potentially, the study could be biased if a particular interviewer is able to elicit more disease-reporting response than other interviewers. Finally, errors of response refer to situations where participants erroneously answer an illness question because of misperception.

I will not discuss exposure assessment except to mention that this is obviously a critical link in epidemiologic studies. If an increase in illness had been found in a community group residing nearer a treatment plant and if some increased levels of viable organisms could be measured in the air, then we would certainly feel more confident about attributing this to aerosol exposure. Unfortunately, sampling methodology has many limitations, and it is currently very difficult to measure exposure accurately in these situations.

Finally, when association is demonstrated between disease and exposure, there are a number of explanations which would account for this association other than a causal relationship. To evaluate the likelihood that an association is causal, a set of criteria is used. These criteria are briefly reviewed here, with particular attention to how they could be applied to studies of wastewater aerosol health effects (Table 6). The strength of the association is measured by the ratio of disease rates for those with and without the exposure. Thus, if the incidence of a particular illness in a population exposed to aerosols were four times the incidence in an unexposed population, the association would be much stronger than in a situation where the incidence is only two times as great in the exposed group, assuming the statistical significance is similar in both cases. The strength of the association reflects the magnitude of the effect and is one of the most important causal indicators. Closely related to this concept is the criteria of a dose-response relationship. Is the magnitude of effects observed greater with a greater exposure? This gradient would be examined around sewage treatment plants by relating illness rates to geographic proximity or meteorological conditions. Occupational exposures would be expected to produce a greater risk than general community exposures. The consistency of an association refers to the persistence of effects from one study to another, under varying conditions, and with the use of differing methodologies. Replication of results adds strength to the idea that the association found is not a chance result and not a spurious association resulting from confounding or bias. Thus, it is important to examine the consistency of findings in the various investigations to be presented at this symposium. The specificity of the association refers to the degree to which the effect is

Table 6. Elements of Causation

Strength of the association
Specificity of the association
Consistency of the association
Temporal relationships
Biological plausibility
Dose-response relationship
Experimental validation

always associated with the exposure and the extent to which the risk factor predicts the occurrence of adverse effects. Specificity is related to strength of association. Because the health effects measured in these studies have a variety of causes, and because a single pathogenic agent can cause multiple clinical syndromes, this criterion is not as crucial to the establishment of a cause-and-effect relationship. However, the linking of a specific disease to a specific exposure is one of the greatest indicators of causation. Temporal factors are very important in the investigation of acute infectious disease. Is the time of occurrence of disease logically related to the hypothesized exposure? In terms of community exposure to treatment plants one could ask: Is an increased illness incidence related to the time of start-up of operation, or to times of increased production of viable particles? An additional temporal concern with regard to infectious disease is the incubation period, defined as the time from first exposure to onset of symptoms. Incubation periods vary widely. While the common cold occurs in several days of exposure, enteroviruses, which are of primary interest in sewage aerosols, have incubation times of 1 to 2 weeks. It might, therefore, be possible to relate a known acute exposure to subsequent illness after an appropriate delay time. This would certainly provide strong etiologic evidence.

Biological plausibility is a very logical criteria for causation. Certain infectious processes, such as respiratory and gastrointestinal diseases, appear far more plausible than others, such as urinary tract infection, where inhalation does not conform to any known pathogenic mechanisms. However, one must be cautious not to reject an association merely because it does not obviously fit expected disease patterns.

The final criteria, experimental validation, is probably not directly applicable to these epidemiologic investigations. An experimental situation that would certainly be feasible is a pre- and post-control technology experiment. In this case, disease rates would be measured during and following known exposure to determine if a decrease in illness was associated with aerosol suppression.

In summary, I have mentioned a number of topics relevant to the design and performance of epidemiologic studies of acute infectious disease. In assessing the investigations to be presented at this symposium, one should be aware of these issues, as a sound epidemiologic approach is essential to gathering data that will help to answer the fundamental questions regarding wastewater aerosol exposure and disease.

DISCUSSION

MR. McCABE: If the people are irate because of the "stinking thing" across the street, how would you handle that?

DR. MIDAY: Well, I think that you have raised a very logical concern, particularly when you are assessing illness by asking people when they experience symptoms. In that situation, I think you would be very limited and you will have to rely on whatever dose response relationship you could hope to develop, plus the use of more objective measures. The consistency of the disease and the confirmation of the diseases reported with known pathogenic mechanisms would be very important here. But you are correct that you have to be very careful in knowing what influenced people when they were reporting their illness experience.

DR. DEAN: This problem of epidemiological investigation looks very good and very easy for a chemist. I know we were asked how we could chemically determine what was in our advanced waste treatment purified wastewater, and we looked at the chemistry and said we can't possibly do it by chemistry. Let's ask the epidemiologist. I went down to ask them and they had a nice conference going on in North Carolina and they started off by saying that the epidemiology was so darn complicated that they needed to know the chemistry before they could give us an answer. This was passing the buck at its highest stage.

Actually, when you are trying to look for nothing you have to look infinitely hard. We have to strike a balance between how much work we are going to do and how important it is to find the answer.

DR. FLIERMANS: One thing that is important with serology is that it tells you what but it doesn't tell you where.

DR. MIDAY: Yes, I didn't point that out very clearly, but you are right. That is why it would be very important to know other factors that would play a part in an individual developing an antibody response. However, if you are studying a large population group and you see definite patterns associated with geography or associated with other exposures, then you can be much more confident that the exposure was not obtained at some other place such as work, school, travel, etc.

DR. DEAN: Well, we have had a good start in today's program. I think that today has helped us to find out how difficult it is to come up with any answers at all, and the following days we will see how successful people have been when they have looked for answers.

Acute Illness Differences with Regard to Distance from the Tecumseh, Michigan, Wastewater Treatment Plant

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ABSTRACT

Acute illness incidence differences with regard to distance from an activated sludge wastewater treatment plant were determined from data obtained as part of a comprehensive community health study conducted from 1965 to 1971 in Tecumseh, Michigan. The additive minimum discrimination information statistic was used to test for significant differences in the incidence of total, respiratory, and gastrointestinal illnesses among individuals dwelling in a series of 600 m concentric rings radiating from the wastewater treatment plant.

When specifying socioeconomic factors, education and income exerted an unequal influence on illness incidence variation and, in general, such variations between geographic locations were found to be greatest in groups having the lowest income and education. The group within the 2,400 m perimeter concentric ring, which had a higher income and education level than the other groups, had a greater than expected incidence of all illnesses. Differences in illness incidence occurred during the May through October season at varying distances from the wastewater treatment plant, but persons within 600 m had a greater than expected risk of respiratory and gastrointestinal illness. Persons dwelling within 600 m of the plant had respiratory illnesses that exceeded those expected by 20% and 27%, and gastrointestinal illnesses that exceeded those expected by 78% and 50% when specified for income and education, respectively. The data suggest that the higher illness rates are related to higher densities of lower socioeconomic families rather than to the wastewater treatment plant.

Centralized processes of wastewater treatment aid sanitation efforts in populated areas throughout the world. Most of these processes produce aerosols that can become windborne and be carried from the site of treatment. These aerosols can contain many of the chemical and biological substances found in wastewater. It is well documented that bacterial aerosols are emitted from these treatment processes and that they can be carried varying distances from the site of origin, depending upon environmental conditions (1). Although existing methodology is below the required sensitivity for the routine isolation of animal viruses from the airborne emissions of wastewater treatment facilities (2), enteroviruses have been reported from aerosols emitted from wastewater spray irrigation processes (3,4).

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Although the health significance of exposure to such emissions has not been adequately determined, some evidence is available. Ledbetter et al. (5) showed that wastewater treatment plant workers had a higher incidence of influenza than water treatment plant workers, and Katzenelson et al. (6), in a retrospective study, showed that persons living in agricultural communal settlements practicing wastewater spray irrigation had a higher incidence of shigellosis, salmonellosis, typhoid fever, and infectious hepatitis than those who lived in settlements that did not irrigate with wastewater, although the mode of transmission (aerosols, person-to-person contact with field workers, etc.) was not determined.

Before undertaking extensive epidemiological studies regarding the health effects of wastewater treatment facilities, existing data were utilized for the evaluation of these effects. The city of Tecumseh, Michigan, was selected as a study site because an intensive community health study, conducted by the University of Michigan, provided an opportunity to utilize uniquely comprehensive data on the epidemiological experience of an entire community.

The purpose of the study was: 1) to determine whether there are differences in incidence of acute infectious illness, depending upon population dwelling distance from a wastewater treatment facility; and 2) to determine the suitability of Tecumseh, Michigan, as a site for a long-term prospective study regarding the influence of wastewater treatment upon the health of exposed populations.

METHODS

Recruitment and Surveillance

Procedures for recruitment and surveillance have been previously described by Monto et al. (7). The dwelling units of Tecumseh, Michigan, were divided into 10 samples by stratified random sampling from each of five geographic strata described by Napier (8).* This sampling procedure resulted in 10 sets of households with characteristics exemplary of the entire community. Each of the households within the 10 samples was randomly ordered for visit by trained interviewers. For purposes of a study of acute respiratory infections, 18 to 24 families were introduced per sample, with exception of the first 6 months of the study when 48 families were recruited per sample. This family recruitment was interrupted during late 1966 upon completion of the tenth sample and then resumed in March 1967. Until May 1967, eligible study families contained parents under age 45 and at least one child of school age or younger. After this date, as part of a chronic bronchitis study, families containing older adults were gradually added using the methods described. Data were obtained from the participating families regarding health history, socioeconomic factors, employment locations, and schools attended by all children.

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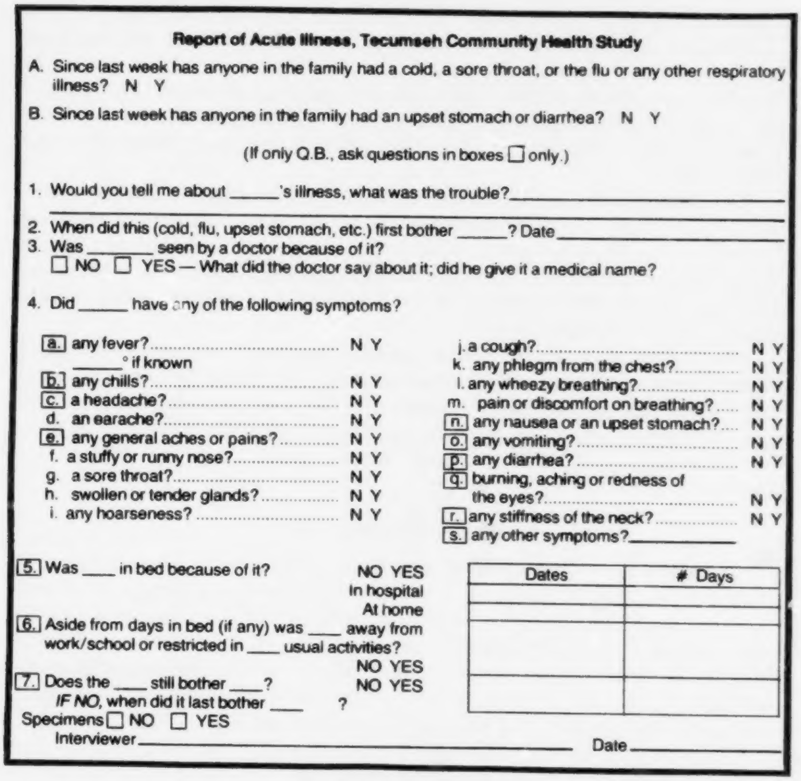
*The last of the six strata described by Napier, scattered new construction found during 1959 and 1960, was not included in this study.



Report of Acute Illness, Tecumseh Community Health Study

A. Since last week has anyone in the family had a cold, a sore throat, or the flu or any other respiratory illness? N Y

B. Since last week has anyone in the family had an upset stomach or diarrhea? N Y

(If only Q.B., ask questions in boxes ☐ only.)

1. Would you tell me about _____'s illness, what was the trouble?____________________

2. When did this (cold, flu, upset stomach, etc.) first bother _____? Date________________
3. Was _______ seen by a doctor because of it?
☐ NO ☐ YES — What did the doctor say about it; did he give it a medical name?

4. Did _____ have any of the following symptoms?

a. any fever? .... N Y
_____° if known
b. any chills? .... N Y
c. a headache? .... N Y
d. an earache? .... N Y
e. any general aches or pains? .... N Y
f. a stuffy or runny nose? .... N Y
g. a sore throat? .... N Y
h. swollen or tender glands? .... N Y
i. any hoarseness? .... N Y
j. a cough? .... N Y
k. any phlegm from the chest? .... N Y
l. any wheezy breathing? .... N Y
m. pain or discomfort on breathing? .... N Y
n. any nausea or an upset stomach? .... N Y
o. any vomiting? .... N Y
p. any diarrhea? .... N Y
q. burning, aching or redness of the eyes? .... N Y
r. any stiffness of the neck? .... N Y
s. any other symptoms?__________

5. Was ____ in bed because of it? NO YES
In hospital
At home
6. Aside from days in bed (if any) was ____ away from work/school or restricted in ____ usual activities?
NO YES
7. Does the ____ still bother ____? NO YES
IF NO, when did it last bother ____ ?

Dates	# Days

Specimens ☐ NO ☐ YES
Interviewer____________________ Date__________

Figure 1. Questionnaire used in the investigation of acute infections in Tecumseh (7) (Reprinted with permission).

After recruitment, each family was contacted weekly by telephone or personal visit and a single respondent was questioned regarding the occurrence of short-term illness within the family during the past week. When illness was reported, the details of the specific event were recorded using the questionnaire shown in Figure 1. The respondent was contacted during the weeks following the initial report and asked whether the illness persisted and to describe the symptoms. The date of illness termination, if any, was obtained and the respondent was questioned regarding other illness development within the family. An illness occurring at least 2 days after a termination date was regarded as a new event.

Study Population Selection

The study population was defined as those participants in the University of Michigan Tecumseh Community Health Study from 1965 to 1971 who resided in dwelling units at specific distance ranges from the Tecumseh wastewater treatment plant (WWTP), located in the southeast quadrant of the city (Figure 2). Dwelling units located within each of five concentric rings and beyond, radiating from the plant in approximate multiples of 600 m, were identified. The dwelling units within the study area were primarily single family houses, although multiple family units occurred at various locations within the area. Confirmation of dwelling unit locations near concentric ring boundaries was made by site visitation.

The population used in nonseasonal-related analyses included those individuals who were contacted at least 50 weeks in a row with no absences during 4 or more weeks. The illnesses included are those whose onset occurred within this 50-week period. The entire population on report from 1965 to 1971 was used for determination of illness incidence rates per person year.

As used in this study, colder months included November through April whereas warmer months included May through October. In each case, the study population was defined as those persons on report for the entire 26-week period, with no long periods (2 weeks or more) off report. The illnesses included are those whose onset occurred during the 26-week period.

Illness Classification

Acute illnesses were grouped into three general categories: total, respiratory, and gastrointestinal. Data are reported as incidence rates and as individual illness rates. Age-sex-distance-specific incidence rates were determined by dividing the number of each kind of illness by the number of person-years observed within each group. Age-sex-distance-specific individual illness rates were calculated by number of illnesses during report period per number of weeks on report.

Statistical Analyses

The objective of the statistical analyses was to determine whether the incidence of illness varied with distance of the dwelling unit from the wastewater treatment plant. Ancillary information for each respondent included age, sex, education of the head of the household, and family income.

The null hypothesis was that the proportion of persons in the high incidence category was the same in the subsets defined by distance from the index point. The distribution of respondents by age, sex, and family income or education level varied from one distance category to another. The test statistic for the null hypothesis was a chi-square goodness-of-fit test in which the expected frequencies were computed by summing the expected frequencies for each age and sex group. The test was conditional upon the family income or education of persons observed in each distance category.

Let O_{ijkl} be the observed number of individuals in the i^{th} age-sex group, in the j^{th} distance interval from the index point, in illness category k, and in family income or education level l where:

$i = 1,2. . . , 18$: where there are nine sex-specific age intervals
$j = 1,2, . . . , 6$: the six distance intervals determined by the five concentric rings about the index point.

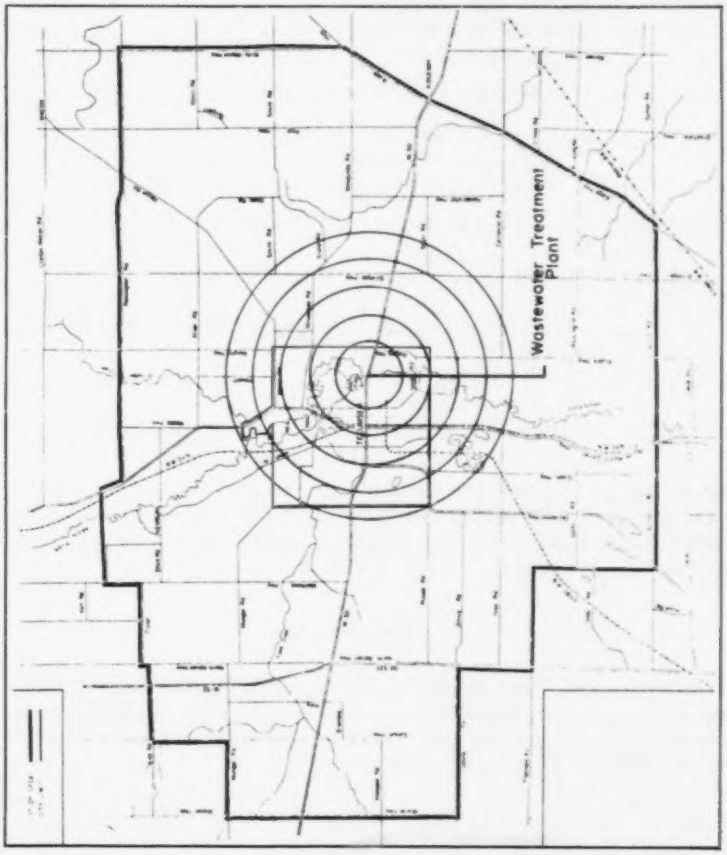

Wastewater Treatment Plant

Figure 2. Location of Wastewater Treatment Plant and 600 m Concentric Rings in Tecumseh Study Area

k = 1,2: the illness categories where
1: n or fewer illnesses in the interval
2: n+1 or more illnesses in the interval where n was selected for each analysis according to type of illness and duration of interval.

l = 1,2,3: the family income or education level, depending on the analysis, where:

(Family Income)

1: less than $7,000
2: $7,000 to 9,999
3: $10,000 or more

(Education of Household Head)

1: less than high school diploma
2: high school diploma
3: some college or college degree.

Then summing, the following counts were obtained:

$0_{.j..} = \sum_{ikl}\sum\sum 0_{ijkl}$: the number of individuals in the j^{th} ring

$0_{i...} = \sum_{jkl}\sum\sum 0_{ijkl}$: the number of individuals in the sample in the i^{th} age-sex group

$0_{i.k.} = \sum_{jl}\sum\sum 0_{ijkl}$: the number of individuals in the age-sex group who are in illness category k

$0_{...l} = \sum_{ijk}\sum\sum 0_{ijkl}$: the number of individuals in income or education level l.

Assuming, as specified by the null hypothesis, that illness category was independent of distance from the index point, the expected number of individuals in the i^{th} age-sex group at family income or education level l at distance j in illness category k was:

$$X_{ijkl} = \frac{0_{i.k.}0_{i..l}}{0^{2}_{i...}} 0_{.j..}.$$

Thus, within the i^{th} age-sex group, the expected number of individuals in the jkl^{th} cross-classification was proportional to the marginal totals. The expected number of persons at distance j in illness category k and at family income or education level l was:

$$X_{jkl} = \sum_{i} X_{ijkl}.$$

The hypothesis of equality of illness rates in the distance categories for a given socioeconomic level was the conditional hypothesis for fixed, but not specified, socioeconomic levels. The test was a joint test on the three levels simultaneously. The test statistic was the sum of the minimum discrimination information statistics, described by Kullback (9) and Kullback et al. (10), for the three individual tests:

$$2I = \sum_{l} 2I_{l} = \sum_{l} 2\sum 0_{jkl} \ln \frac{0_{jkl}}{X_{jkl}}$$

with degrees of freedom l(j-1) (k-1), the sum of the degrees of freedom for the individual tests. Significant departures of the observed from the expected frequencies, as indicated by the test statistic, led to rejection of the null hypothesis against the alternative of an association between high illness rates and distance from the index point. To determine that, among persons at family income or education level l, the proportion in the high incidence category was the same in all subsets as defined by distance from the index point, a test was performed separately on each level l. The statistic was the minimum discrimination information statistic,

$$2I_l = 2\Sigma 0_{jkl} \ln \frac{0_{jkl}}{X_{jkl}}$$

distributed as chi square with (j-1) (k-1) degrees of freedom.

Wastewater Treatment Plant Description

The Tecumseh wastewater treatment plant (WWTP) was located in the southeast quadrant of the city (Figure 2). The plant was at a lower elevation than most of the populated study area and was surrounded by deciduous trees on the east, west, and south. This plant processed approximately 1 mgd of wastewater by activated sludge secondary treatment. Activated sludge had been in use since 1965, when the plant was redesigned from a trickling filtration facility. Data that might have been used to estimate the fecal contribution to the wastewater, such as total or fecal coliform concentrations, were not available for the study period. Wastewater flow rates for the study period were not available from the Tecumseh WWTP, but available data were obtained from the Michigan Department of Natural Resources.

RESULTS

Sewage Flow

Average monthly sewage flow rates at the Tecumseh WWTP ranged between 0.64 and 1.18 mgd from 1965 to 1971. Data, however, were not available for 1966, and some data for 1965, 1968, and 1969 are missing. As shown in Figure 3, the lowest sewage flow rates were observed during 1965 and the highest monthly average was seen in 1968. Although flow rate fluctuations are observed, no consistent flow pattern is evident among the study years.

Illness Incidence

Age-sex specific individual illness rates per person-year for the Tecumseh study population during 1965 to 1971 are presented in Figure 4. In general, illness incidence rates were higher in females than in males and, although demonstrating a slight increase at ages 20 through 30, varied inversely with age in both sexes. The lowest incidence rates were observed for the gastrointestinal illness classification.

Socioeconomic Distribution

Of the 4,889 study participants, data are available on 3,627 and 4,877 individuals for income and education, respectively, of the household head. The distribution of individuals at specified distances from the

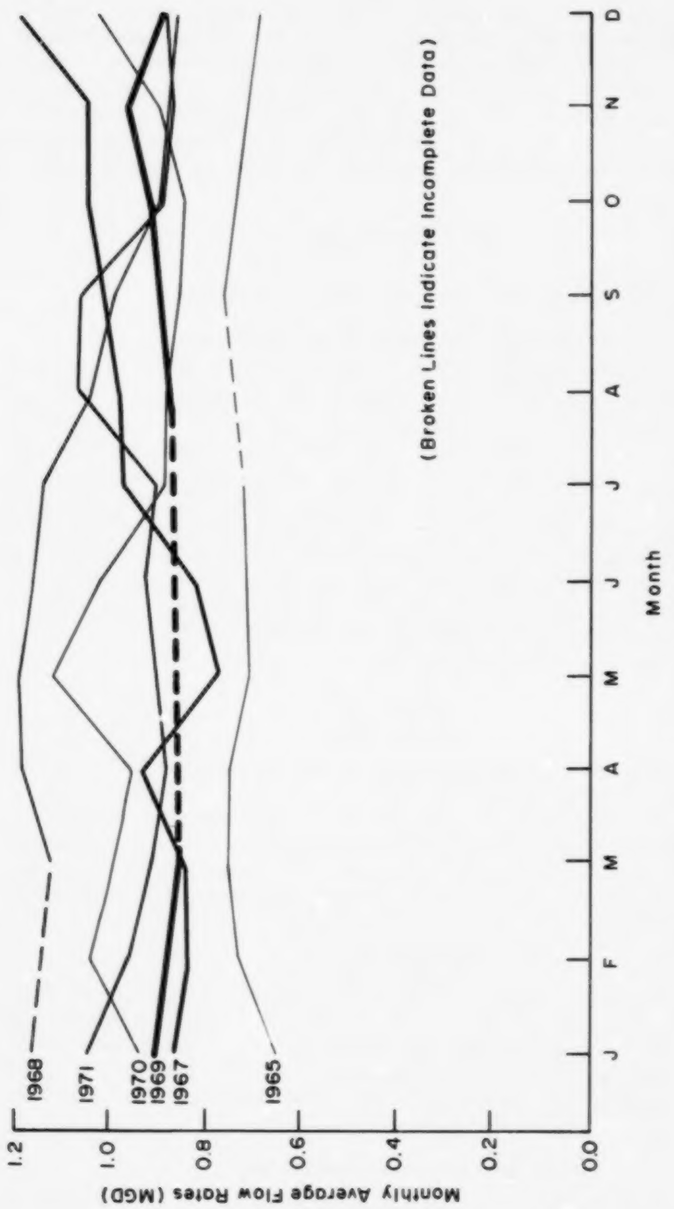


Figure 3. Monthly Average Sewage Flow Rates for the Tecumseh, Michigan, Wastewater Treatment Plant from 1965 to 1971 (Source: Michigan Department of Natural Resources)

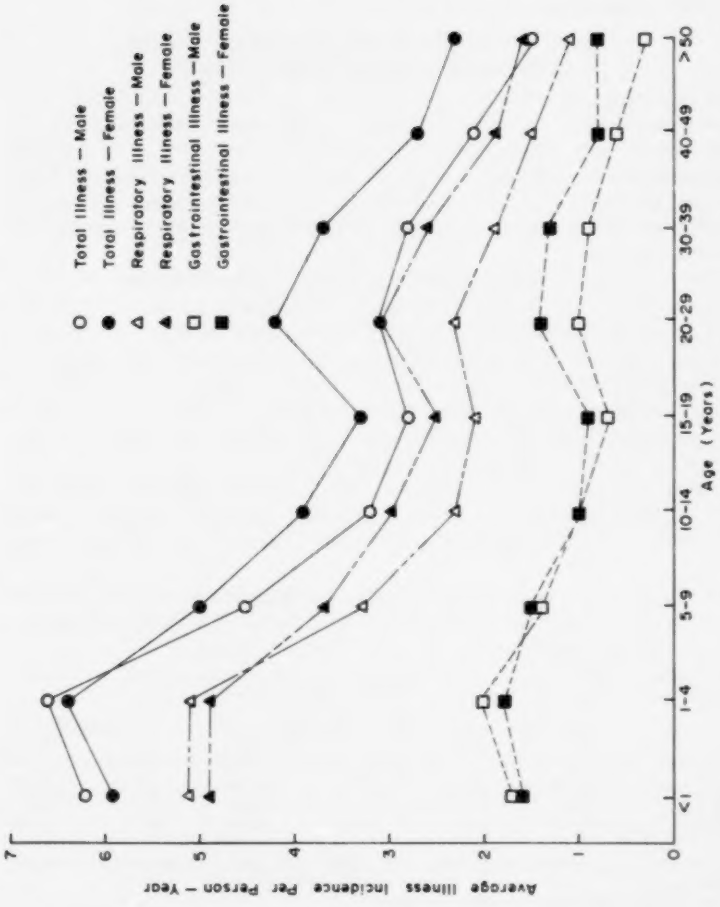


Figure 4. Average Acute Illness Incidence/Person-Year in Tecumseh Study Area, 1965 to 1971

WWTP having household heads with income or education within high, moderate, and low income or education categories was examined. Figure 5 shows the percent excess [((observed-expected)/expected) × 100] individuals in each income and education category in each concentric ring from the WWTP. The figure illustrates that the highest percent excess number of individuals in the lowest income and education classification are located within the 600 m perimeter concentric ring while those in the highest income and education category are located within the 2,400 m perimeter concentric ring.

ILLNESS INCIDENCE BY DISTANCE FROM WASTEWATER TREATMENT PLANT

For analyses, the number of persons having four or more total, three or more respiratory, or one or more gastrointestinal illnesses during the report period was determined. Consequently, the number of persons reported in the total illness category is not necessarily the sum of those in respiratory and gastrointestinal illness classifications since the criteria for inclusion within a specific group are based upon different numbers of illness occurrences.

Table 1 illustrates the summed income- and education-specific information statistic for illness occurrences at varying distances from the WWTP. Significant education-specific illness incidence variations were observed over the total study period in all three illness classifications and during the colder months in the gastrointestinal illness classification. Differences in income-specific respiratory illnesses were seen during all study periods and in income-specified total illnesses during the entire study period and during the warmer months.

Considering each family income and education classification separately, Table 2 shows that illness incidence variations among persons living in the six different concentric rings was greatest in those individu-

Table 1. Summed Income- and Education-Specific Information Statistic for Illness Occurrence at Varying Distances from Wastewater Treatment Plant[a]

Study Period	Illness Classification[b]					
	Total		Respiratory		Gastrointestinal	
	I	E	I	E	I	E
Total	28.31[c]	54.69[d]	28.22[c]	49.98[d]	19.42	25.06[c]
May-Oct.	25.32[c]	25.16	26.38[c]	15.69	20.21	24.37
Nov.-Apr.	21.20	24.60	25.59[c]	19.80	19.65	32.48[d]

[a] Based on illness occurrences at 600; 1,200; 1,800; 2,400; 3,000; and > 3,000 m from wastewater treatment plant

[b] Number of occurrences included in each classification:

Illness	Study Period		
	Total	May-Oct.	Nov.-Apr.
Total	≥4	≥3	≥3
Respiratory	≥3	≥2	≥2
Gastrointestinal	≥1	≥1	≥1

[c] 95% confidence level based on 15 degrees of freedom

[d] 99% confidence level based on 15 degrees of freedom

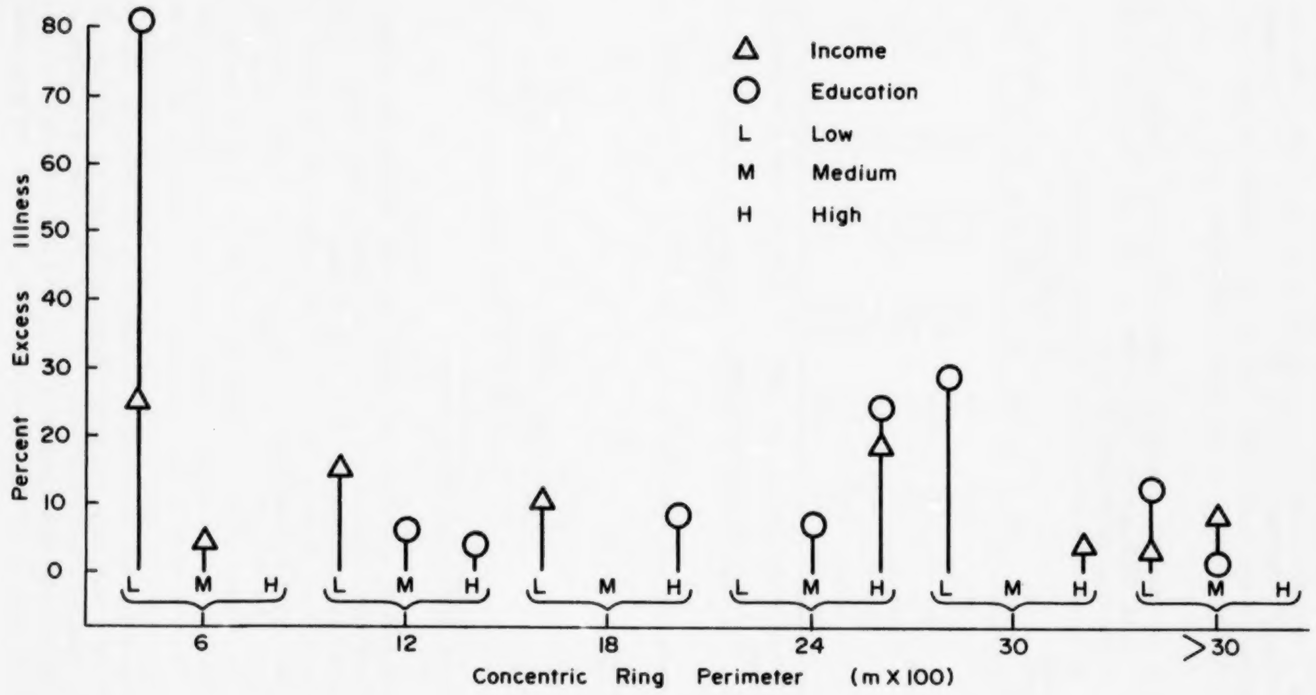


Figure 5. Percent Excess Education and Income of Household Head by Distance from Wastewater Treatment Plant

als in the lowest income and education classification. The differences for total gastrointestinal illnesses were significant during all three study periods when specified for education. With the exception of the moderate income total illness classifications, no significant illness variations were seen at the higher income or education classification.

Table 2. Income- and Education-Specific Information Statistic for Illness Occurrence Differences at Varying Distances from Wastewater Treatment Plant[a]

Income or education level	Study period	Illness Classification Total		Respiratory		Gastrointestinal	
		Income	Education	Income	Education	Income	Education
Low	Total	13.60[d]	41.59[e]	13.92[d]	44.50[e]	5.87	17.11[e]
	May-Oct.	3.26	14.31[d]	6.28	9.48	5.55	11.53[d]
	Nov.-Apr.	8.81	14.72[d]	15.32[e]	10.79	3.91	22.49
Moderate	Total	11.28[d]	3.33	10.52	0.73	4.91	2.43
	May-Oct.	13.74[d]	7.03	10.27	3.81	9.97	7.66
	Nov.-Apr.	6.80	1.45	7.35	1.60	6.58	3.25
High	Total	3.43	9.77	3.79	4.76	8.64	5.52
	May-Oct.	8.31	3.82	9.84	2.40	4.71	5.18
	Nov.-Apr.	5.58	8.44	2.91	7.41	9.17	6.74

[a] Based on illness occurrences at 600; 1,200; 1,800; 2,400; 3,000; and >3,000 m from wastewater treatment plant

[b] Number of occurrences included in each classification:

Illness	Study period Total	May-Oct.	Nov.-Apr.
Total	≥4	≥3	≥3
Respiratory	≥3	≥2	≥2
Gastrointestinal	≥1	≥1	≥1

[c] *Income*	*Education*	*Level*
>$7,000	Less than high school diploma	Low
$7,000-9,999	High school diploma	Moderate
≥$10,000	Some college or college degree	High

[d] 95% confidence level based on 5 degrees of freedom

[e] 99% confidence level based on 5 degrees of freedom

Summation of education- and income-specific illnesses by distance from the wastewater treatment plant was performed, and percent excess [((observed-expected)/expected) × 100] illnesses for the entire study period is shown in Figure 6. The greatest illness excesses were observed for income-specified gastrointestinal illnesses within the 600 m concentric ring and for total illnesses in the 2,400 m ring. Breaking down the study period observations into the colder and warmer months, Figures 7 and 8 illustrate that excessive illnesses occurred unequally among concentric rings and between the two seasons. For both income- and education-specific illnesses, the number observed exceeded those expected by the greatest amount in the 600 m concentric circle during the warmer months for respiratory and gastrointestinal illnesses. Respiratory illnesses exceeded those expected by 20% and 27% whereas gastrointestinal illnesses exceeded those expected by 78% and 50% when specified for income and education, respectively. Differences of this magnitude

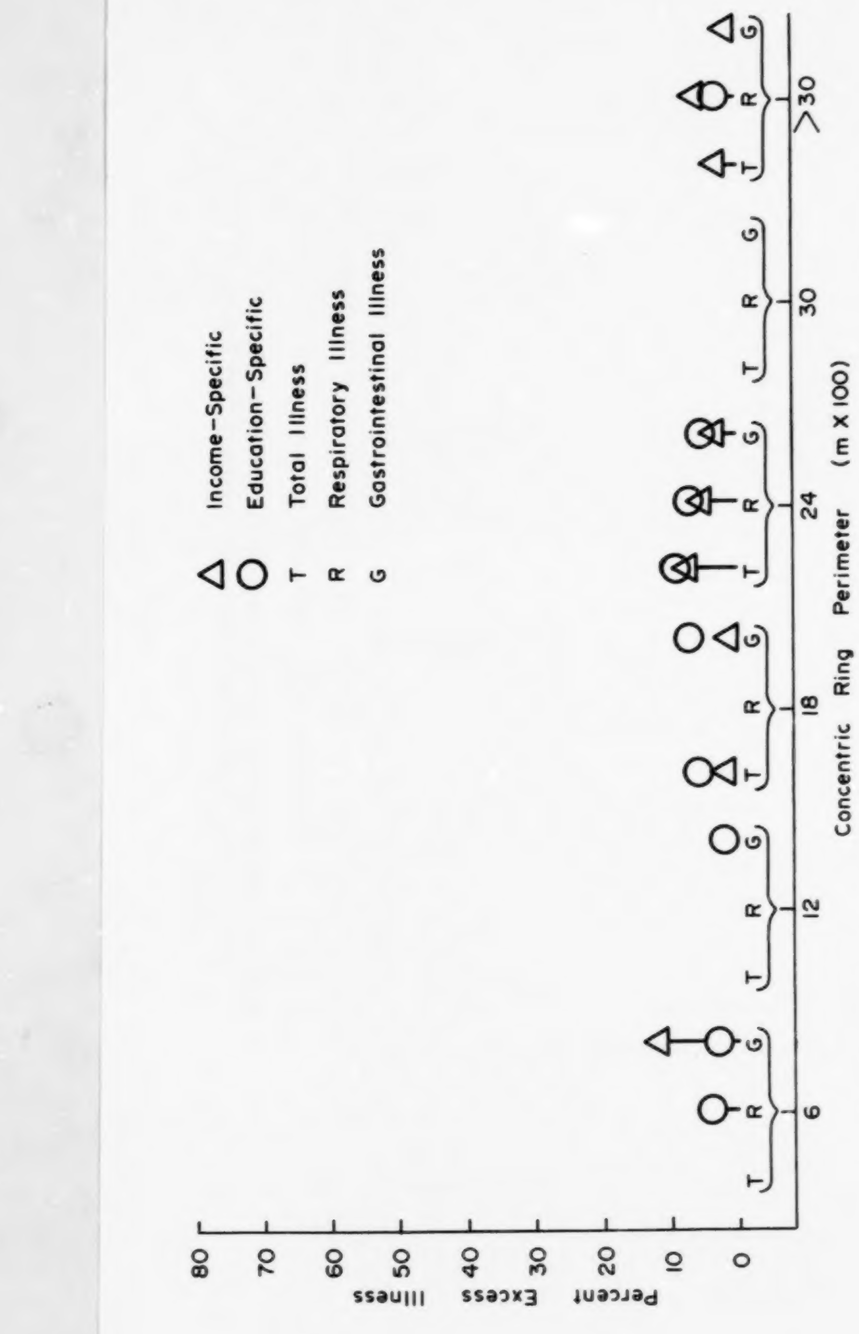


Figure 6. Summed Income- and Education-Specific Illnesses: Percent Excess by Distance from Wastewater Treatment Plant During Study Period

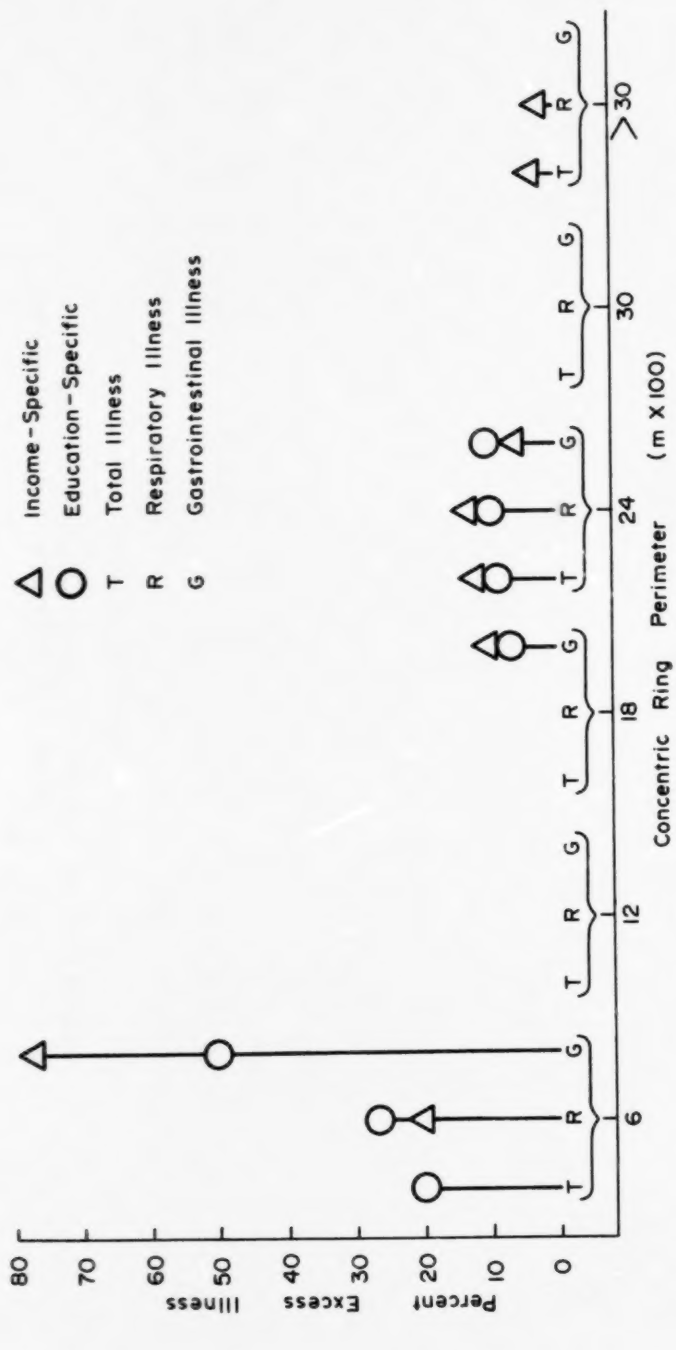


Figure 7. Summed Income- and Education-Specific Illnesses: Percent Excess by Distance from Wastewater Treatment Plant During May to October

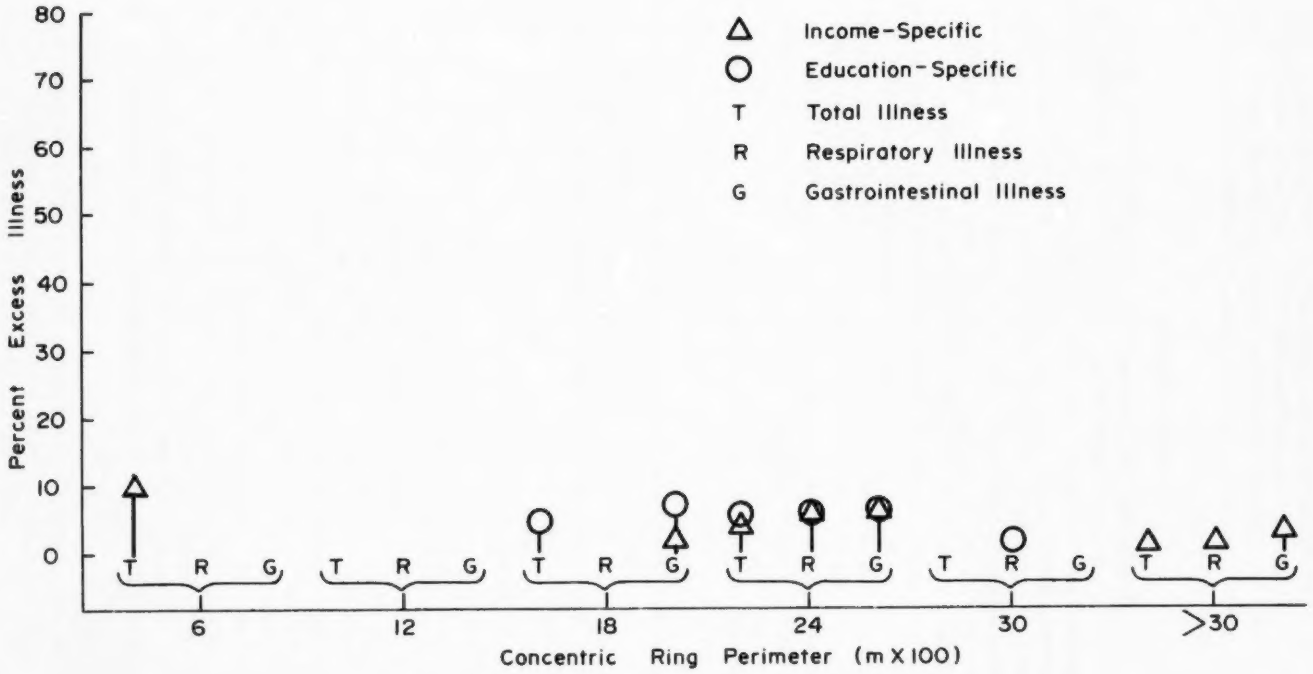


Figure 8. Summed Income- and Education-Specific Illnesses: Percent Excess by Distance from Wastewater Treatment Plant During November to April

were not observed during the colder months nor during the entire study period. Greater than the expected number of illnesses were consistently observed within the 2,400 m WWTP concentric ring for all income- and education-specific illnesses during the warmer and colder months as well as during the entire study period.

DISCUSSION

The Tecumseh, Michigan, wastewater treatment plant is small relative to those which serve larger metropolitan areas. This plant was selected for use in this investigation because of its location within a comprehensive community health study area and because it was not considered to be uniquely different from activated sludge plants serving comparably sized communities. Consequently, the observations made in this study should not be considered unique to Tecumseh but to represent those made with the participation of a highly cooperative community.

In this study, acute illness occurrences in 4,889 people living at six different general locations from a wastewater treatment plant were observed over a 7-year period. More than the expected number of persons living closest to the wastewater treatment plant (within 600 m) experienced income- and education-specific illnesses during May through October. As seen in Figure 5, persons dwelling within 600 m of the wastewater treatment plant had both less education and lower incomes than those dwelling in the more distal locations. The greater-than-expected number of persons developing illnesses nearest the wastewater treatment plant during the summer may be attributable to reduced levels of sanitation within a lower socioeconomic group during a period of higher enterovirus infection incidence. Melnick et al. (11) demonstrated the seasonal distribution of enteroviruses while Monto and Cavallaro (12) confirmed a higher late summer incidence of enteroviral infection in the Tecumseh study population.

The population dwelling within the 2,400 m concentric ring was found to have a consistently greater-than-expected incidence of all education- and income-specific illnesses. The reasons for the greater illness incidence within this group are not readily explainable with available evidence. As shown in Figure 5, persons dwelling within the 2,400 m concentric ring had both higher education and income than did the other study groups. There are no known sources of exposure in the 2,400 m area that would increase the likelihood of increased acute illness.

Although the concentrations of potentially infectious organisms in the Tecumseh sewage are not available for the study period, it is known that potentially pathogenic bacteria and viruses, excreted by the contributing community, survive transport to wastewater treatment facilities (13,14). While the aerosols emitted from the Tecumseh wastewater treatment plant were not characterized as part of this study, it is reasonable to assume that this plant does emit aerosols containing potentially pathogenic infectious organisms, as has been observed with other activated sludge plants studied (1).

The exposure and potential for infection probability of a population to the airborne emissions of a wastewater treatment plant is dependent upon the concentration, survival, and dispersion of aerosolized infectious organisms. It is likely that, if certain community illnesses were attributable to the wastewater treatment plant, such occurrences may not be strictly distance-dependent since local airflow disturbances affect airborne dispersion in a manner not predictable with present methods of estimating diffusion (15). The plant is located at a lower elevation than the portions of the study area containing most of the population and is surrounded on the east, south, and west by deciduous trees. Depending upon wind direction, velocity, and atmospheric stability, surrounding trees may act as a partial barrier for persons dwelling nearest the plant while lofting the airflow, resulting in further downwind dispersion. When exposure does occur, however, the significance of risks of infection is related to the size and density of the population. Evaluation of the effects of such exposure is further complicated by variations of susceptibility to infections and resultant illnesses within an exposed population.

The results of this study suggest that high rates of illness transmission in areas of high densities of lower socioeconomic families is a more important factor in excess illness within a population than is proximity to a small wastewater treatment plant. Excess illnesses within these lower socioeconomic families during the warmer months exceed those observed during the colder months. Higher than expected illness incidence within the highest socioeconomic group, however, cannot be readily explained.

Further prospective study should identify the factors associated with suggested increased illness risks within specified groups. The influence, if any, of the wastewater treatment plant should be determined by detecting areas of probable exposure and resultant illness incidence. A design permitting the estimation of community transmission parameters would enable separation of the influence of the wastewater treatment plant from other potential sources of transmission.

ACKNOWLEDGMENT

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DISCUSSION

MR. LINDAHL: Was any consideration given to the fact that for the period from May through October the windows were open, and for the period from November through May the windows were closed?

DR. FANNIN: There were several reasons for selecting the two periods. There was evidence that during the warmer months there was an increased instance of enterovirus infection within that population, and there was a greater exposure during the summer. It was intended to specify for the time of the year because of expected greater exposure and expected higher instance rates during that season.

MR. LINDAHL: Was any consideration given to the effect of the trees surrounding the basin?

DR. FANNIN: Well, I eluded to that consideration in my discussion, where I indicated that the trees probably did act as a partial barrier for any aerosols that might have been emitted from the plant. They might have disrupted local air flow patterns resulting in relatively unpredictable downwind dispersion.

MR. LINDAHL: One more question. Would you suggest planting trees around the wastewater plant as one of the alternatives to improve the situation?

DR. FANNIN: Yes. I think that is an acceptable method for providing some barrier to a potentially exposed population.

DR. LEDBETTER: I would like to point out something about the statistics that bothers me. On Figure 6 you have 18 different possibilities across there. You have total, respiratory, and gastrointestinal illness. I note that nine of them are blank, that is, don't have any circles or triangles. I presume they turned out negative.

DR. FANNIN: Taking the test indicates excess illnesses only. So, you are correct that the points which don't have figures indicate that fewer than expected illness occurrences were noted at that particular location for that particular illness.

DR. LEDBETTER: Isn't it amazing that it turns out exactly 9 out of 18. It has some above average and some below average. I think we draw a conclusion where there is not any supporting data.

DR. FANNIN: First of all, Dr. Ledbetter, I might note that with the statistical analyses, the thing we were trying to determine was whether there were differences in illness occurrences.

DR. LEDBETTER: I'm really concerned when I look at Figures 6, 7, and 8. Fuller says not to trust those that divide it into parts in order to get big numbers. I think the people that read that article are not scientists, overall, but statisticians.

DR. DEAN: I would like to know how many of your four thousand population were inside the inner circle?

DR. FANNIN: They were unequally distributed throughout the population. I don't have the figures with me but I can tell you that there were fewer individuals in the inner circle.

DR. DEAN: What I want to know is, when you talk about 10 excess cases, how many actual illnesses are you talking about-10, 100, 1,000?

DR. FANNIN: We are talking about fewer than 100, and I don't have the raw data with me, but I can tell you that it was based upon very few illnesses.

DR. DEAN: Well, in the inner circle differences of 20% can't be significant. You have got to have something bigger than that because you are working with such small numbers.

DR. FANNIN: Well, that is true. We are working with small numbers and this study was designed as a preliminary study to determine if there were any detectable differences with regard to distance from the sewage plant. But there are other factors involved, not merely distance in this study.

DR. FUHS: What is your population with respect to the prevailing wind direction?

DR. FANNIN: I have a wind rose of prevailing wind direction which will illustrate this point. The major population center was upwind from the prevailing wind.

I think this is important to consider but I think you should realize that the population in Tecumseh has a very strong data base on comprehensive community health, and that is the reason the city was selected. The location of the plant is very good from a public health point of view, I believe.

DR. LUE-HING: My question has to do with the reference you mentioned from Israel. Are you referring to the reported article in "Science"?

DR. FANNIN: Yes, I am referring to a reported article in "Science."

DR. LUE-HING: I just want to say that I may disagree with the use of the conclusions of the article without the necessary caveats. The data include people not necessarily working in the sprays. Without the caveats, other persons reading the citation may get the wrong impression, and I would hope that would not be the case. My colleagues may disagree but that is my feeling.

Health Effects from Wastewater Aerosols at a New Activated Sludge Plant: John Egan Plant, Schaumburg, Illinois

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ABSTRACT

A study was performed to identify public health hazards of aerosols from operating sewage treatment plants by examining a new activated sludge facility. Environmental monitoring, a household health survey, and assays of clinical specimens from human subjects were conducted during four baseline and operational sampling periods within a 5 km radius of the plant. The residential area began 350 m from the plant.

The wastewater aerosol from the aeration basins was a statistically significant source of indicator bacteria and a presumed source of coliphage, pathogenic bacteria, enteroviruses, and mercury. However, the levels of microorganisms and trace metals in the air in neighboring residential areas were not distinguishable from the background levels.

The nearby residents reported a higher incidence of skin disease and several gastrointestinal symptoms after the treatment plant became operational. Antibody tests for 31 human enteric viruses and attempted isolations of many pathogenic bacteria, parasites, and viruses yielded virtually no clinical evidence of infectious disease effects associated with the sewage treatment aerosol.

At the exposure levels investigated, the sewage treatment aerosols from well-operated American plants do not appear to be a significant health hazard to residential populations. The current evidence is insufficient to determine whether effects of lesser consequence, such as gastrointestinal symptoms and skin conditions, are associated with moderate aerosol exposure.

INTRODUCTION

Background

The United States Environmental Protection Agency, through its construction grants program to the states and municipalities, is funding a multibillion dollar effort to construct new wastewater treatment facilities throughout the United States. These new facilities are required to reduce sewage pollution of the waterways of the nation.

In the past, many wastewater treatment plants have been constructed in relatively unpopulated areas. From an engineering standpoint, however, some facilities must be located close to the residential areas served. Consequently, urban development has placed large populations in close proximity to treatment facilities in recent years.

Locating a wastewater treatment plant near residential areas might pose a health problem because of the wastewater aerosol produced by the plant. Large amounts of wastewater aerosol are generated during secondary treatment by the aeration basins of activated sludge plants and by trickling filters. Pathogenic organisms excreted by infected individuals in the area served by the plant often survive the primary treatment process. Thus, the wastewater aerosol may contain the pathogenic microorganisms of diseases occurring in the service area.

Hickey and Reist (1) and Kowal and Pahren (2) provide a useful summary and evaluation of the literature. It has been adequately demonstrated in the literature that activated sludge and trickling filter treatment processes are a source of aerosolized microorganisms (3-11) which are carried at least 50 m downwind from the aeration basin (4,5,11).

The pathogenic microorganisms in the wastewater aerosol could infect exposed populations, such as workers, nearby residents, and persons passing through the area. There have been few studies designed to examine the potential health effects of a wastewater treatment plant on the surrounding population. Fannin et al. (9) reported increased risk of respiratory and gastrointestinal illness for persons within 600 m of a wastewater plant, but socioeconomic differences in the study populations confound the interpretation of their results. Northrop and coworkers (10) found that a large wastewater treatment plant was a source of microorganisms, but no obvious health effects on residents were evident. Clark et al. (12), in preliminary results, found some evidence of increased subclinical viral infections but none for bacterial infections in workers engaged in wastewater collection and treatment. Katzenelson et al. (13) examined communicable diseases in Israeli populations living near facilities which utilized essentially untreated wastewater and found that the incidences of dysentery, typhoid fever, and infectious hepatitis were higher in populations which utilized the wastewater. The use, however, was not limited to spray irrigation.

This paper reports the results of an environmental monitoring and a prospective epidemiology study of a new activated sludge wastewater treatment plant located near Chicago, Illinois (14).

Objectives

The objectives of this study were: 1) to determine whether sewage treatment processes are a source of bacteria, viruses, and trace metals in aerosols; 2) to identify health effects which might be attributable to a sewage treatment plant.

Study Design

The design was to monitor the environment and the health of persons near a new activated sludge treatment plant before and after its initial operation. The environmental monitoring during the baseline period measured microorganisms and trace metals in ambient air, soil, and surface water. After the plant became operational, the wastewater and the wastewater aerosol were also monitored. A household health survey was conducted on the incidence of respiratory, gastrointestinal, eye, ear, and skin diseases, and symptoms in persons living within 5 km of the plant. This survey was performed both prior to the operation of the plant and after its initial operation. The health of a subgroup of volunteers from the baseline health survey was monitored through isolates of pathogenic bacteria, viruses and parasites in clinical specimens, through viral antibodies in serum, through specimen trace metal levels, and through reported incidence of relevant diseases and symptoms. These persons lived within 3.5 km of the plant. Their health was monitored in early fall and mid-winter both before and after the initial operation of the plant.

Site

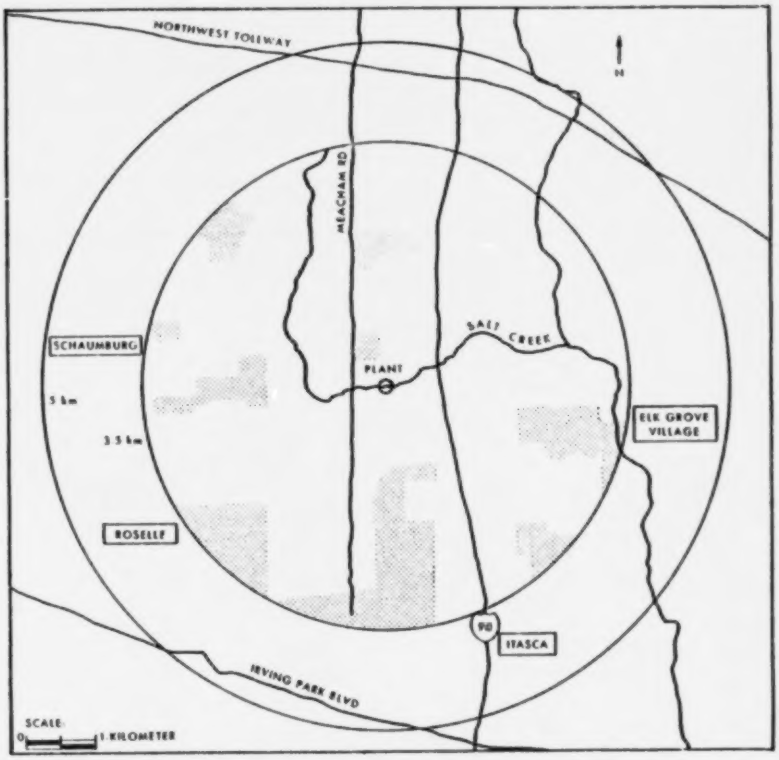
The design of this study (i.e., before and after initial operation) necessitated that a new wastewater treatment plant be selected which was not an addition to an existing plant and that a sufficiently large population reside near the plant site in order to conduct a sensitive health study. The John E. Egan Wastewater Plant of the Metropolitan Sanitary District of Greater Chicago, located near Schaumburg, Illinois, was selected. The Egan plant is a conventional activated sludge plant with a design dry weather flow of 30 mgd (1.4×10^8 l/day). The study site map presented in Figure 1 shows the plant location on Salt Creek. The area shown is located approximately 25 miles northwest of downtown Chicago, Illinois. The study site was divided into two concentric regions (within 3.5 km and from 3.5 to 5.0 km) about the Egan plant. The design permitted the use of distance and prevailing wind direction(s) as surrogate measures of exposure. The presumably least exposed subjects provided a control population with similar socioeconomic and demographic characteristics.

Daily resultant wind directions from the U.S. Weather Bureau at O'Hare International Airport showed that prevailing winds were from the southwest and south and secondarily from the north-northeast during the operational period of the study. Thus it was anticipated that exposure to aerosols from the plant aeration basin would be less for residences located to the west and northwest than in other directions. The wind rose diagram, giving the distribution of daily resultant directions from which the wind blew during the operational period, is presented in Figure 2.

METHODS

Environmental Monitoring

Air and Wastewater Sampling. Air samples were taken simultaneously upwind and at several distances downwind from the plant. Continuous meteorological measurements for wind speed, wind direction, and relative humidity were made by an on-site weather station. Microbial air samples were collected by use of large volume electrostatic precipitator air samplers (LEAP and Litton types). Sampling runs were conducted for 30 min at a sampling rate of 1.0 m^3 of air/min. A typical sampler array was one upwind sampler with four or five samplers at various


NORTHWEST TOLLWAY
N
MEACHAM RD
SALT CREEK
SCHAUMBURG
PLANT
5 km
3.5 km
ELK GROVE VILLAGE
ROSELLE
90
ITASCA
IRVING PARK BLVD
SCALE
0
1 KILOMETER

Note: Shaded areas show location of participants from which clinical specimens were obtained.

Figure 1. Map of study area around John E. Egan Sewage Treatment Plant.

distances from 15 to 300 m downwind. A wastewater sample was collected from the aeration basin during sampling to allow comparison with air levels of the monitored microorganisms.

Large volume composite samples of wastewater were collected from the aeration basin to indicate the relative prevalence of routine indicator organisms and selected pathogens. A more comprehensive screen of two grab samples was conducted to identify and provide semiquantitative data on potentially pathogenic organisms.

Bacteriology. Wastewater and air samples were analyzed for indicator and potentially pathogenic organisms by procedures detailed in Standard Methods, the 13th edition (15) or 14th edition (16). Total and fecal coliform were determined using the membrane filter [redacted]6), and standard count was determined according to Standard Methods (16) using an automatic colony counter.

Virology. The enterovirus assay of wastewater and air samples was performed using a bentonite concentration method with enumeration on

LOCATION	O'HARE INTERNATIONAL AIRPORT CHICAGO, ILLINOIS
PERIOD	JANUARY – OCTOBER 1976
OBSERVATION	DAILY RESULTANT WIND DIRECTION
NO. OF OBSERVATIONS	305 DAYS
SOURCE	LOCAL CLIMATOLOGICAL DATA, NATIONAL CLIMATIC CENTER

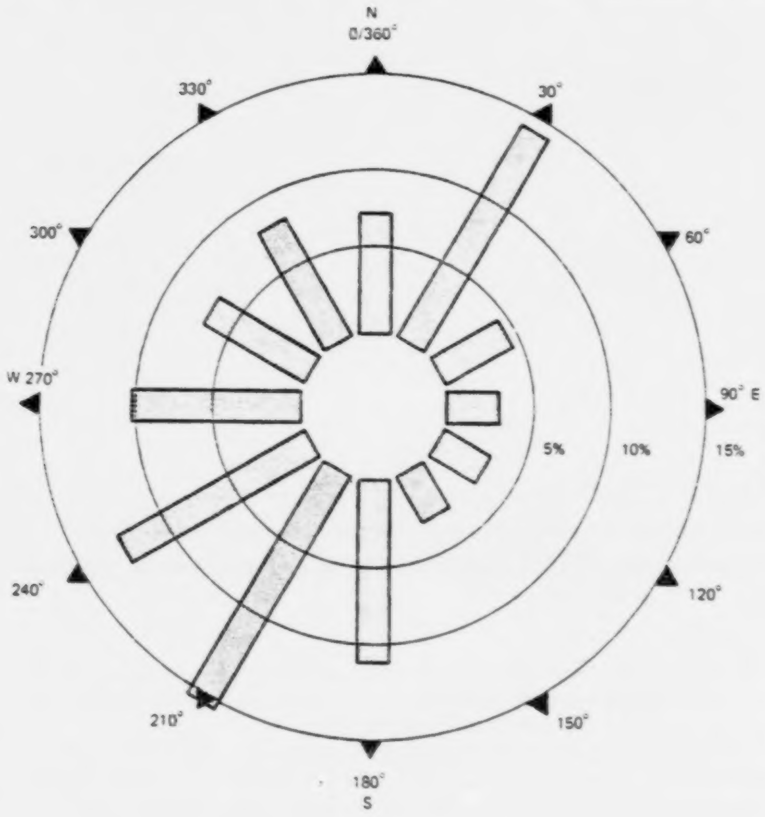


Figure 2. Distribution of daily wind direction during the operational period (Jan.–Oct. 1976)

HeLa cell monolayers and reported as pfu/l original sample (17). Two-thirds of the plates of each assay were incubated for three days and scored for plaques. To avoid overgrowth of slower-growing enteric viruses by poliovirus plaques, the remaining one-third of each sample was mixed with pooled antipolio serum, incubated for five days and scored for plaques.

Household Health Survey

Design. Household surveys were conducted prior to plant operation (baseline survey) and after its initial operation (operational survey) to collect demographic and health information on residents who lived in the study area. The baseline survey also served as a basis for recruitment of participants. During each of the two survey periods, approximately 1,100 households were contacted, about one-half in the inner concentric circle and the balance in the outer concentric region. The two regions were divided into 22 sectors, 12 in the inner circle and 10 in the outer region. A stratified sampling by sector was conducted, and approximately 50 households were interviewed in each. The head of the household or spouse was asked to complete a questionnaire on each person in the household regarding demographic characteristics and occurrences of selected chronic and acute diseases and symptoms.

Households. The characteristics of the local residents are presented in Table 1, based on the 1970 census tracts wholly or partially within the 5 km radius study area. The area population was considered sufficiently large to conduct the health study. It consisted primarily of white, middle to upper-middle class residents who lived in single family homes.

The baseline survey in September 1974 was conducted in 1,043 households between 1 and 5 km from the plant site. The study design had scheduled the operational survey for September 1975, but initial operation of the plant was delayed until December 1975. In the meantime, an apartment complex was opened very close to the plant site (from 350 to 800 m northwest of the first-stage aeration basin). Accordingly, in September 1975 an additional 75 baseline surveys were conducted in this new community of nearby residents. After the treatment plant began operation, 1,104 household surveys were obtained in September 1976.

A total of 1,118 households with 4,428 members were included in the baseline survey, and 1,104 households with 4,269 members were included in the operational survey. The two survey samples were compared to determine any differences in personal and demographic charac-

Table 1. Characteristics of Residents (1970 Census)

Age	Number	
Less than 5	13,238	Median income—$6,000
5–19	35,265	Median education—12.5 years
20–44	38,514	Race—99.3% white
45+	12,435	Occupational status—31.3% professional or managerial
	99,452	

teristics. Fewer children, especially those less than nine years of age, were involved in the operational survey than in the baseline survey. Also, there were fewer children within 2 km of the plant site in the operational survey.

Diseases and Symptoms. The questionnaire obtained a report from the household head or spouse on the occurrence of acute diseases within the last 12 months and symptoms within the last three months for each person in the household. Table 2 shows a list of diseases and symptoms monitored. Prior to data analysis, these diseases and symptoms were evaluated by a physician to identify the likelihood of association with possible pathogens in sewage treatment aerosols and to identify the age group expected to have the highest incidence rate. This evaluation was used in interpreting the results.

Table 2. Diseases and Symptoms Monitored in Household Health Survey

Diseases

Polio
Pneumonia
Skin disease
Spinal meningitis
Croup
Anemia
Empyema
Infectious jaundice
Worms
Pleurisy
Influenza
Sleeping sickness
Dysentery

Symptoms

Severe headache not relieved by aspirin
Severe dizziness
Severe night sweats
Canker sores around mouth
Sore throat
Cold
Diarrhea
Bloody diarrhea
Bloody urine
Burning on urination
Yellow skin
Weakness of arms or legs
Stiff neck with fever
Stiff neck with rash
Fever above 103°F
Colicky pains in abdomen
Shortness of breath
Unconsciousness (not due to blow on head)
Severe pain in bones and joints with high fever
Severe weight loss
Hemorrhagic rash
Yellow eyeballs
Cough
Skin rash: face
Skin rash: arms and legs
Skin rash: body
Nausea
vomiting
Pain in chest on deep breathing
Cough up blood
General weakness
Draining ear
Severe trouble with teeth
Brown urine
Convulsions

Statistical Methods. The data from the Household Health Survey are in the form of frequency counts of reported occurrence of a particular chronic illness, disease, or symptom. The statistical methodology determined any significant changes in the rate of occurrence between the baseline period and the operational period. In addition, any change in incidence rate associated with the distance of the household to the Egan plant was determined. When both conditions were met, i.e., the incidence rate of a disease or symptom was significantly higher in the operational period than in the baseline period, and incidence rate increase was highest in households within 2 km of the Egan plant, then the sewage treatment plant was considered for its potential as the source.

A multiple approach was used for this evaluation. First a contingency table was constructed with factors of survey period at two levels (baseline and operational) and distance at three levels (0 to 2.0 km, 2.0 to 3.5 km, and 3.5 to 5.0 km). Using chi-square test of independence, the incidence of each illness, disease, and symptom was tested for significant interaction or dependence between distance and survey period. Diseases or symptoms exhibiting this tendency were compared to the physician's evaluation for likelihood of a relationship to the treatment plant and for age group expected to show highest incidence.

As a second method of evaluation, the relative incidence in the baseline and operational periods were compared. The test statistic was a standard normal deviate, Z, calculated to test the null hypothesis of equivalent proportions in the two surveys in the same distance range. The same test was also used for the incidence rates for the three distances separately to determine if any change in incidence had a distance pattern consistent with the hypothesis of a plant effect on community health. To identify possible plant effects, the difference measure, Z_1, at the 0 to 2.0 km range, had to be more strongly positive than at the remaining distances, Z_2 and Z_3, and for the overall trend in the study area, Z_0.

For those diseases and symptoms for which a possible effect was identified, the relative incidence was determined for the four wind direction quadrants, and the incident rates in the prevailing downwind directions (north and south) were examined.

Since many incidence rates vary with age or sex, the possibility that this was the cause of the observed changes in incidence was investigated by comparing the incidence rates within age and sex subgroups at the closest distance for each disease and symptom possibly identified with the plant.

Clinical Specimens

Human Subjects. A total of 231 participants began the study in October 1974, 51 participants from the close-in apartment complex were added in October 1975, and 226 completed the clinical specimen health monitoring in October 1976. The majority of the 20 percent of participants who dropped out of the study did so because they relocated, and there was no attempt to replace them. Blood, feces, urine, blood, throat swabs, sputum, and hair were collected during each of the four periods.

The characteristics of the 226 study participants who finished the study are given in Table 3. The plan had been to collect equal numbers of participants in each of the eight age-sex groups, but the need to include parents to obtain the participation of young children resulted in overrepresentation of the 19-45 age group. The participants were pre-

Table 3. Characteristics of Participants

Age	Sex	
	Male	Female
0–6	20	26
7–18	27	20
19–45	43	55
46+	15	20
	105	121

Race: 96% white
Education: 49% of heads of households completed college

dominantly white, in accord with the racial distribution of the area residents (Table 1). Some 49% of the heads of participant households had completed college, indicating that selected volunteer participants were better educated than the community as a whole. Regarding the distribution of ages, the participants were particularly representative of the general population:

Participants	*Residents*
42% 18 years or less	49% 19 years or less
43% 19-45 years	39% 20-44 years
15% 46 years or more	12% 45 years or more

The distribution of participants relative to distance from the center of the plant was as follows:

Distance (km)	*Number of Participants*
0.3—0.6	34
1.4—1.9	35
2.0—2.9	113
3.0—3.5	44

The 34 participants living close to the plant (350 to 600 m from the primary aeration basin) all resided in the apartment complex northwest of the plant location. Since the prevailing winds are from the north and south and seldom from a southeasterly direction, these 34 participants were usually upwind from the plant's aerosol emissions.

Bacteriology. Pathogenic and potentially-pathogenic bacterial isolates were sought from the feces, sputum specimens, and from the throat swabs. Sputum specimens were only analyzed for *Mycobacterium tuberculosis.* Fecal specimens and throat swabs were analyzed for each of the following pathogens and potential pathogens: 1) *Proteus;* 2) *Pseudomonas;* 3) *Salmonella;* 4) *Shigella;* 5) *Staphylococcus aureus;* 6) *Staphylococcus epidermidis;* and 7) *Streptococcus*-beta.

Fecal Specimens. Bacteriological examinations of feces were performed in accordance with the standard procedures and techniques which have been established for isolation and identification of microorganisms by clinical diagnostic laboratories and by procedures standard for the conducting laboratory. Feces samples were inoculated onto *Salmonella-Shigella* agar, endo agar, eosin-methylene blue agar, and MacConkey agar plates for primary isolation. Cultural morphology, biochemical reactions, microscopic appearance, and serologic testing were employed as required.

Throat Swabs. Bacteriological examinations of throat swabs were performed in the same manner as the feces samples. Throat swabs were inoculated primarily onto blood agar plates.

Sputum. Sputum specimens were inoculated onto Lowenstein-Jensen Medium and Middlebrook 7H-10 Medium in screw cap tubes and incubated in a CO_2 incubator.

Parasitology. Seven hundred eighty-nine fecal specimens were analyzed for a variety of helminths (parasitic worms) and protozoa. Parasites and commensals from the following groups were sought: Helminth-Nematodes, Helminth-Cestodes, and Protozoa. The merthiolate-iodine-formalin concentration technique (MIFC) proposed by Blagg et al. (18) was used.

Virology. The fecal specimens and throat swabs were both analyzed for a spectrum of virus groups and associated microorganisms:

adenovirus
arbovirus
arenavirus
coronavirus
herpesvirus
oncornavirus
orthymyxovirus
paramyxovirus
papovavirus
picodnavirus
picornavirus
poxvirus
reovirus
rhabdovirus
other viruses
chlamydia and ricksettia

Fecal Specimens. Isolation and identification of viruses from feces were performed by standard procedures (19) and by procedures of the NIH/WHO Regional Reference Center for Simian Viruses. Monolayer cell cultures of primary baboon kidney and cultures of a continuous cell line (WI-38) were employed for demonstration of cytopathology.

Throat Swabs. Virologic examinations of throat swabs were performed by the methods used for feces. Primary isolation was performed on primary baboon kidney cells and WI-38 cell monolayers.

Viral Serology. Two sets of viral serology tests were conducted on the blood samples. Eight tests were conducted on all participant blood samples to measure the antibody levels to the following viruses: Coxsackievirus B-1; Echoviruses 3, 7, 11, and 12; and poliovirus 1, 2 and 3.

A second set of 23 additional serologic tests was conducted on the paired October sera of 100 selected participants, which were classified into three groups of presumably different aerosol exposure. Group I (28 participants) resided in the apartments just northwest of the plant within 0.3 to 0.6 km. Group II (39 participants) resided within 1.4 to 2.3 km and primarily to the south. Group III (33 participants) resided within 2.8 to 3.5 km of the plant mainly to the northwest. The groups were well matched for age, sex, and socioeconomic status with a higher frequency of smokers and central air-conditioning in Group I. The 23 additional tests for these 100 paired sera were as follows: Adenoviruses 1, 2, 3, 4, and 5; Coxsackievirus A-7, A-9, A-16, B-3, B-5, and B-6; Echoviruses 4, 6, 8, 13, 19, 21, 25, 29, and 33; and Reoviruses 1, 2, and 3.

Serological analyses were performed by standard procedures (19). The specific test systems employed were hemagglutination-inhibition and serum neutralization. Each viral serology test determined the concentration range of the viral antibody in a blood sample by a titration procedure. Most tests used six serial two-fold dilution levels: 1 in 10, 20, 40, 80, 160, and 320. Poliovirus tests were conducted at two tenfold dilution levels (1 in 10 and 1 in 100), because poliovirus antibody levels presumably resulted from vaccinations.

Statistical Methods. The statistical analysis of the clinical specimen microbiology had two major objectives: 1) to determine from the self- and seasonally-paired data whether there were increases in the incidence of pathogen isolates or antibody titer rises in the operational sampling periods, and, if so; 2) to determine whether such increases were related to surrogate aerosol exposure measures such as distance from the sewage treatment plant, or to other factors such as participant characteristics. Participants residing between 350 and 600 m from the aeration basin comprised a separate analysis group termed the "close-in" participants.

In order to determine whether the occurrence of pathogen isolates in the clinical specimens and viral antibody titers had increased after the plant began operating, the analytical results of the samples taken from each participant were matched according to season (February or October) and compared for each of the bacteria, parasites and viruses analyzed in the four sample media (feces, throat swabs, sputum, and blood). Comparisons of the paired isolation results from bacterial, parasitic, or viral analyses of feces, throat swab, or sputum samples yielded three possible outcomes: decrease, increase, or no change from the baseline to the operational sampling period. Through a series of two-sided sign tests, paired samples showing an increase or decrease were analyzed; incomplete pairs were deleted. All of the microbiological isolation data were analyzed in this way.

Each serologic test result was reported as a viral antibody titer. Consecutive integer codes were assigned to the geometric series of titer levels and difference scores were computed from the codes for paired sera. Wilcoxon's one-sample signed ranks tests were applied to the difference scores to determine whether the presence of antibodies to these viruses had increased in the operational year. The analysis of the 23 additional serology tests required comparison of antibody changes observed in the three defined groups having presumably different levels of aerosol exposure. The Kruskal-Wallis H test was used, followed by planned comparisons to elucidate distance-exposure relationships.

All pathogens showing an overall increase in occurrence or in titer level in the operational periods were further investigated through stepwise multiple regression to determine if the pattern of increases was associated with surrogate measures of aerosol exposure. The 34 potential regressor variables consisted of possible plant aerosol exposure factors (e.g., distance, prevailing downwind directions, hours per day at home), other environmental factors, and personal factors.

RESULTS

Environmental Monitoring

Wastewater. Table 4 shows a summary of the data for the microbial analyses of wastewater from the primary aeration basin. While *Salmonella* and *Shigella* were not detected, *Klebsiella*, mycobacteria, *Pseudomonas* and fecal streptococci were found at relatively high levels. Low concentrations of human enteroviruses (primarily polioviruses) were seen, and they were primarily associated with solids (approximately 98%). The first stage aeration basin had substantially higher levels of coliforms than did the second stage.

Air Sampling. Table 5 shows a summary of the data from microbiological assay of air samples. Measurable levels of standard plate count, total coliform, fecal coliform, coliphage, fecal streptococci, and *Pseudomonas* were found above background at near downwind sites. *Proteus*, *Klebsiella*, *Salmonella*, *Shigella*, and enteroviruses were not detected. Statistical examination of these data revealed that the wastewater plant

Table 4. Microbial Concentrations in Aeration Basin

Standard Analyses (Geometric Mean)	
Standard Plate Count, SPC/ml	5,800,000
Total coliform, cfu/ml	400,000
Fecal coliform, cfu/ml	21,000
Coliphage, pfu/ml	120
Fecal streptococci, cfu/ml	1,300
Pseudomonas, cfu/ml	10,000
Proteus, cfu/ml	<3
Salmonella, cfu/ml	<3
Shigella, cfu/ml	<3
Enteroviruses, pfu/ml	
Three-day	0.2
Three- and five-day	0.2
Bacterial Screen (Semiquantitative)[a]	
Clostridium, cfu/ml	6
Enterobacter, cfu/ml	2,000
Klebsiella, cfu/ml	8,000
Leptospira, cfu/ml	30
Mycobacteria, cfu/ml	1,000
Staphylococcus, cfu/ml	2,000

[a] Bacterial screening results are geometric means from 2 grab samples.

Table 5. Microbial Aerosol Concentrations

(Microorganism Geometric Mean)	Upwind	15–25 m	50–80 m	95–200 m
Standard Plate Count, SPC/m^3	4,400	29,000	9,000	7,100
Total coliform, cfu/m^3	1.3	12.4	6.9	3.1
Fecal coliform cfu/m^3	0.2	0.7	0.5	0.03
Coliphage, pfu/m^3	0.02	0.08	0.04	0.02
Fecal streptococci, cfu/m^3	<2	<2	15	<2
Pseudomonas, cfu/m^3	<4	50	<4	4
Proteus, cfu/m^3	<2	<2	<2	<2
Salmonella, cfu/m^3	<2	<2	<2	<2
Shigella, cfu/m^3	<2	<2	<2	<2
Enteroviruses, pfu/m^3	<0.02	<0.02	<0.02	<0.02

was an aerosol source of standard plate count, total coliform, and fecal coliform but that the elevated levels returned to background levels at residential distances.

Large volume aerosol samplers are necessary to provide the sensitivity to obtain quantitative microorganism aerosol concentrations, especially for pathogens. However, the large volume samplers have a tendency to become and remain contaminated with some of the hardy microorganisms, such as *Pseudomonas*, usually resulting in an extremely high standard plate count.

Six-stage Andersen samplers were used to determine particle size distribution of microbiological aerosols. The limited standard plate count and total coliform size data suggest that about half of the viable particles were in the primary respirable range (between 1 and 5 μ in diameter).

The first stage aeration basin was determined to be a borderline significant source of aerosolized mercury. However, there was no difference in the mercury levels between the residential upwind and residential downwind locations. The aeration basin was not a detectable source of Cd or Pb, since there was no significant difference between their upwind and close downwind levels in air.

Household Health Survey. From the chi-square tests of independence, the incidences of the following diseases and symptoms were determined to exhibit a significant interaction or dependence between distance and survey period at the one percent level: influenza, vomiting, asthma-hay fever, and worms. Significant at the five percent level were dysentery, general weakness, nausea and sore throat.

Based on the physician's evaluation of possible sewage treatment association, asthma-hay fever and worms were considered unlikely to be related and were eliminated from further consideration. It was the physician's judgment that the remaining symptoms might be associated with sewage treatment aerosol exposure.

As a result of the Z tests (standard normal deviate), three additional diseases or symptoms were implicated as possibly being associated with sewage treatment aerosol exposure: skin disease, diarrhea, and pain in chest on deep breathing. Each of these responses showed a significant increase at the 0 to 2.0 km range and nonsignificant changes at the greater distances. The reported incidence of the identified illnesses, diseases, and symptoms in each of the three distance ranges in the baseline period and operational period is presented in Table 6, and the test statistics for significance for each identified response are presented in Table 7. As shown in Table 6, all responses, except asthma-hay fever, worms, and sore throat showed an increased relative incidence (percentage incidence) at the 0 to 2.0 km range which is suggestive of sewage treatment aerosol exposure. This was further demonstrated by the significant chi-square and positive Z_1 values in Table 7 for each of the responses.

Further examination of these symptoms for an association with prevailing wind directions showed that there was an increase in the southern inner sectors for all the diseases and symptoms possibly identified in the prior analyses as associated with aerosol exposure, and in the northern inner sectors for all but two. Since these were the two predominant downwind directions during the operational period, the consistency of

Table 6. Incidence of Illnesses, Diseases, and Symptoms Reported in The Household Health Surveys

	Baseline survey		Operational survey	
	Number of responses N		Number of responses N	
Household members surveyed				
0.0 - 2.0 km	750		644	
2.0 - 3.5 km	1711		1621	
3.5 - 5.0 km	1951		1992	
	Positive responses n	Percentage incidence p	Positive responses n	Percentage incidence p
Chronic illnesses ever diagnosed				
Asthma - hay fever				
0.0 - 2.0 km	102	13.6%	72	11.2%
2.0 - 3.5 km	188	11.0%	182	11.2%
3.5 - 5.0 km	176	9.0%	235	11.8%
Diseases diagnosed during past year				
Dysentery				
0.0 - 2.0 km	2	0.3%	3	0.5%
2.0 - 3.5 km	22	1.3%	1	0.1%
3.5 - 5.0 km	13	0.7%	7	0.4%
Influenza				
0.0 - 2.0 km	70	9.3%	72	11.2%
2.0 - 3.5 km	221	12.9%	122	7.5%
3.5 - 5.0 km	366	18.8%	182	9.1%
Skin disease				
0.0 - 2.0 km	4	0.5%	11	1.7%
2.0 - 3.5 km	28	1.6%	21	1.3%
3.5 - 5.0 km	27	1.4%	27	1.4%
Worms				
0.0 - 2.0 km	7	0.9%	0	0.0%
2.0 - 3.5 km	27	1.6%	0	0.0%
3.5 - 5.0 km	11	0.6%	14	0.7%
Symptoms experienced in Past 3 months				
Diarrhea				
0.0 - 2.0 km	31	4.1%	49	7.6%
2.0 - 3.5 km	73	4.3%	77	4.8%
3.5 - 5.0 km	94	4.8%	86	4.3%
General weakness				
0.0 - 2.0 km	5	0.7%	12	1.9%
2.0 - 3.5 km	17	1.0%	7	0.4%
3.5 - 5.0 km	29	1.5%	11	0.6%
Nausea				
0.0 - 2.0 km	9	1.2%	19	3.0%
2.0 - 3.5 km	41	2.4%	23	1.4%
3.5 - 5.0 km	59	3.0%	33	1.7%
Pain in chest on deep breathing				
0.0 - 2.0 km	4	0.5%	12	1.9%
2.0 - 3.5 km	27	1.6%	24	1.5%
3.5 - 5.0 km	28	1.4%	22	1.1%
Sore throat				
0.0 - 2.0 km	132	17.6%	59	9.2%
2.0 - 3.5 km	269	15.7%	195	12.0%
3.5 - 5.0 km	333	17.1%	243	12.2%
Vomiting				
0.0 - 2.0 km	10	1.3%	20	3.1%
2.0 - 3.5 km	52	3.0%	23	1.4%
3.5 - 5.0 km	53	2.7%	47	2.4%

Table 7. Test Statistics for Significance of Responses

Illness, disease, or symptom	Chi-square	Z_0	Z_1	Z_2	Z_3
Asthma-hay fever	13.19[a]	1.43	−1.36	0.22	2.85[a]
Influenza	15.06[a]	−8.64	1.14	−5.12	−6.73
Worms	24.98[a]	−3.90[a]	−2.48[b]	−5.06[a]	0.56
Vomiting	12.04[a]	−1.48	2.27[b]	−3.15	−0.71
Dysentery	10.03[b]	−3.63	0.62	−4.27	−1.39
General weakness	10.40[b]	−2.17[b]	2.03[b]	−1.92	−2.93[a]
Nausea	10.04[b]	−2.26	2.32[b]	−2.05[b]	−2.84[a]
Sore throat	8.45[b]	−6.55[a]	−4.57[a]	−3.08[a]	−4.33[a]
Skin disease	4.27	0.22	2.12[b]	−0.82	−0.08
Diarrhea	4.20	1.07	2.78[a]	0.67	−0.83
Pain in chest on deep breathing	4.89	0.12	2.32[b]	−0.23	−0.93

[a] Significant at 0.01 level. Required: X^2 – 11.34, Z – 2.58.

[b] Significant at 0.05 level. Required: X_2 – 7.84, Z – 1.96.

these results lends some credence to the possibility that these reported changes in general health status may be associated with sewage treatment aerosol exposure.

In examining incidence by age and sex subgroups, the lower proportion of young children in the operational survey may explain the reported incidence reductions in worms, sore throat, and high fever. However, it increases the likelihood that the reported higher incidence of gastrointestinal systems was actually associated with aerosol exposure. A summary of the results from the health survey is presented in Table 8.

Clinical Specimens

Bacterial Isolates. *Proteus*, *Pseudomonas*, and *Salmonella* were the only pathogen isolates in the feces samples; fecal streptococci were frequently isolated but are not considered pathogenic. Statistical analysis showed a significant decrease in the incidence of *Proteus* isolations in the operational periods and no significant differences in the isolation incidences of *Pseudomonas* or *Salmonella* between the baseline and operational periods. There were significant increases in the incidence of throat swab isolates of *Streptococcus*-beta and *Staphylococcus aureus* in the operational periods. However, regression analysis of the incidence pattern with distance and direction from the plant indicated that the increases were not related to the participants' exposure to sewage treatment aerosols. No *Mycobacterium tuberculosis* was isolated in any sputum sample.

Parasitic Isolates. Protozoa were found in eleven samples; none contained helminths. The protozoans were identified and their frequencies were *Chilomastix mesnili* (1), *Entamoeba coli* (4), *Entamoeba hartmanni* (1), *Endolimax nana* (1), *Giardia lamblia* (3), and *Trichomonas* (1). Depending on the sampling period, from 0 to 2 percent of the participant samples contained parasites. The incidence of parasitic isolates from feces increased slightly in the operational period; however, improvements in sample collection and processing during the operational sampling periods may be responsible for the increased incidence.

Table 8. Summary of Health Survey Analyses

Illness, disease, or symptom	Test for independence	Physician's evaluation	Distance relationship	Direction relationship
Asthma-hay fever	Significant at 0.01	Not related	None	—
Influenza	Significant at 0.01	Related	Slight increase at 0-2, decrease overall	Increase at close distance in south
Worms	Significant at 0.01	Possibly related	None	—
Vomiting	Significant at 0.01	Related	Significant increase 0-2, slight decrease elsewhere	Increase at close distance north and south
Dysentery	Significant at 0.05	Related	Slight increase 0-2, decrease elsewhere	None
General weakness	Significant at 0.05	Related	Significant increase 0-2, significant decrease elsewhere	Increase at close distance north and south
Nausea	Significant at 0.05	Related	Significant increase 0-2, significant decrease elsewhere	Increase at close distance in south
Sore throat	Significant at 0.05	Related	None	—
Skin disease	Not significant	Possibly related	Significant increase 0-2, no change elsewhere	Increase at close distance north and south
Diarrhea	Not significant	Related	Significant increase 0-2, no change elsewhere	Increase at close distance north and south
Pain in chest on deep breathing	Not significant	Not related	Significant increase 0.2, slight decrease elsewhere	Increase at close distance north and south

Viral Isolates. No viruses were found in the throat swabs. All 20 of the positive virus isolates in the feces samples were picornaviruses. The picornavirus group includes polioviruses, coxsackieviruses, echoviruses, and rhinoviruses. The picornavirus isolation comparison results were evaluated through a sign test which indicated that there had been a significant increase in picornavirus isolations in the operational sampling periods (see Table 9). Comparison with the serologic titers showed that subjects with picornavirus isolates had titer rises to a variety of echo and coxsackie viruses, but there was little correlation of the isolates with titer rises and seroconversions. Regression analysis was then used to determine whether the pattern of isolation increases conformed to plant aerosol exposure. The resulting equation explained very little of the variability in the pattern of increases, and the two potential exposure factors identified exhibited the wrong relationship to be associated with aerosol exposure (isolations decreased with exposure and were greater

Table 9. Comparative Analysis of Viral Isolations in Feces Samples

	Results of paired comparisons[a]				
		0			Total
	—	(N)	(P)	+	Pairs
Picornavirus					
Original participants–February	2	176	2	5	185
Original participants–October	0	145	0	7	152
Lexington Green participants–October	0	28	0	0	28
Total comparisons	2	349	2	12	365
Result: significant increase, p = 0.016					

[a] – = the pathogen was isolated in the baseline period sample, but was not isolated in the paired operational period sample

0 = the paired baseline and operational period samples both contained the pathogen (P), or both were negative for the pathogen (N)

+ = the pathogen was isolated in the operational period sample, but not in the baseline period sample

northwest of the plant). Thus, there is no evidence that the sewage treatment aerosol was related to the increase in picornavirus isolates.

Viral Serology. Table 10 summarizes the difference scores from the paired comparisons of the titers to Echovirus 12 and Poliovirus 1, two of the eight specific tests conducted on all serum samples. The statistical analysis of the paired comparisons determined whether the presence of the antibodies to those viruses in human blood samples had increased in the operational year. Only antibodies to these two viruses demonstrated significant changes between baseline and operational samples. Titers to Echovirus 12 declined significantly in the operational period (p = 0.045). Titers to Poliovirus 1 rose significantly after the sewage treatment plant began operation (p = 0.014). Regression analysis was used to determine whether the pattern of Poliovirus 1 titer rises was consistent with plant aerosol exposure. The resulting equation provided no evidence of association with the plant's aerosol.

Analyses comparing Groups I, II, and III were conducted for the 23 additional serologic tests. Antibody titer difference scores are presented in Table 11 for three of the 23 viruses for which possible antibody changes were found. Only the changes in antibody to Echovirus 29 were significantly different among the three groups (p = 0.02). There was a borderline significant difference among the groups in Echovirus 13 antibody (p = 0.07), and a difference approaching significance for the changes in antibody to Echovirus 33 (p = 0.18).

If the plant aerosols were contributing to the presence of viral antibody in the blood, it is plausible that the effect would be proportional to exposure. The negative exponential of distance from the Egan aeration basin may be a good surrogate measure of long-term cumulative exposure to the microbiological aerosol (20). Based only on this exposure measure, the close-in participants (Group I) were expected to evidence

Table 10. Summary of Viral Antibody Titer Comparisons from Original Tests on All Human Subjects

	Results of paired comparisons[a]							Total
	−3	−2	−1	0	+1	+2	+3	pairs
Echovirus 12 by hemagglutination-inhibition								
Original participants–February	0	1	14	176	8	0	0	199
Original participants–October	0	5	16	165	10	2	0	198
Lexington Green participants (October)	0	0	2	26	2	0	0	30
Total comparisons	0	6	32	376	20	2	0	427
Result: significant decrease, p = .045								

	Results of paired comparisons[a]					Total
	−2	−1	0	+1	+2	pairs
Poliovirus 1 by serum neutralization						
Original participants–February	0	2	173	6	0	181
Original participants–October	0	0	155	10	0	165
Lexington Green participants (October)	0	2	28	1	0	31
Total comparisons	0	4	356	17	0	377
Result: significant increase, p = .014						

[a] A code difference of 1 corresponds to a twofold titer level change for echovirus and tenfold for poliovirus

the greatest increase in viral antibody titer, followed by the nearer original participants (Group II). Planned contrasts were conducted on the Echovirus 29 antibody data; a borderline significant increase in titer rises occurred in Group II relative to Group III ($p = 0.05$).

An increase in antibody titer of at least a factor of four in paired sera is generally defined as seroconversion, indicating an immune response to infection. Of the three Echovirus 29 seroconversions among the 100 paired sera, two (a seven-year old girl and her father who lived nearly 2 km south of the aeration basin) were from Group II and the other from Group III. In an effort to determine what factors were contributing to the pattern of titer rises, the Echovirus 29 difference scores were regressed. The regression equation provided little evidence of an association between Echovirus 29 titer rises and exposure to the plant aerosol.

In general, the serology analyses provided little evidence of the sewage treatment aerosol as a source of virus. For the one virus exhibiting an overall increase in antibody titer (Poliovirus I), there was no evidence at all of the expected relationship of plant aerosol exposure to the observed titer rises. The Echovirus 29 results provide possible evidence of an exposure-related pattern in the original participants, but no effect occurred in the close-in participants who were seldom downwind.

Trace Metals. Clinical specimen trace metal data from blood, feces, hair, and urine appeared unrelated to the presence of the sewage treatment plant. Trace metals analyzed were Cd, Cu, Pb, Hg, and Zn.

Table 11. Summary of Viral Antibody Titer Comparisons from Additional Tests on 100 Human Subjects

	Results of paired comparisons[a]					Total
	−2	−1	0	+1	+2	pairs
Echovirus 13 by hemagglutination-inhibition						
Group I (Lexington Green participants)	0	3	25	0	0	28
Group II (Original participants-near)	0	0	36	1	2	39
Group III (Original participants-far)	0	2	29	1	1	33
Total comparisons	0	5	90	2	3	100
Result: borderline significant difference, p = .07						
Echovirus 29 by hemagglutination-inhibition						
Group I (Lexington Green participants)	0	1	27	0	0	28
Group II (Original participants-near)	0	0	32	5	2	39
Group III (Original participants-far)	0	2	29	1	1	33
Total comparisons	0	3	88	6	3	100
Results: significant group difference, p = .02						
Echovirus 33 by serum neutralization						
Group I (Lexington Green participants)	0	0	27	1	0	28
Group II (Original participants-near)	0	1	35	3	1	39
Group III (Original participants-far)	0	2	31	0	0	33
Total comparisons	0	3	93	4	1	100
Results: approaching significant difference, p = .18						

[a] A code difference of 1 corresponds to a twofold titer level change

DISCUSSION

Significance of Findings

Source of Wastewater Aerosol. The wastewater aerosol from the Egan aeration basins constituted a significant aerosol source of total and fecal coliforms and the standard plate count of aerobic and facultative anaerobic heterotrophic bacteria. The sampled wastewater concentrations and projections using the microbiological dispersion model (20) suggest that the aeration basins were also a source in early October 1976 of such potential pathogens as *Klebsiella*, *Pseudomonas*, and fecal streptococci. One would expect the potential pathogens prevalent in the aerosol source to vary with the cyclical epidemic pattern of the associated diseases in the community serviced by the sewage treatment plant. *Salmonella* and *Shigella*, for example, were not prevalent at that time. With the possible exception of Hg, the Egan wastewater aerosol did not appear to be a significant source of trace metals, especially relative to vehicular traffic and industrial point sources.

Environmental monitoring did not detect higher than background levels of indicator coliforms and the standard plate count at the distances of the nearest residences (350 to 600 m). This is to be expected in light of model projections of the downwind levels (20), and the sensitivity of the air samplers. Similar results were obtained from extensive distant monitoring at a wastewater spray irrigation site (21, 22).

Reported Symptoms and Illness. There were statistically significant increases in the self-reported incidence of skin disease, of a gastrointestinal syndrome (diarrhea, nausea, vomiting, and general weakness), and of pain in chest on deep breathing in the surveyed households within 2 km of the sewage treatment plant. These increases occurred primarily in the predominantly downwind quadrants (north and south) and were not observed in the households more distant (2 to 5 km) from the plant.

The proportion of young children was smaller in the operational period survey, both in the total survey population and in the households within 2 km of the plant. This age disparity might explain the statistically significant decreases in the reported incidence of sore throat, and fever above 103 F, both of which are more common in young children. However, it fails to explain and accentuates the anomaly of obtaining the reported higher incidence of the gastrointestinal symptoms near and downwind from the plant.

Thus, the elevated reported incidence of gastrointestinal symptoms and skin disease might have been associated with the wastewater aerosol from the Egan plant. Suitable infectious agents were present in the wastewater (e.g., enteroviruses and atypical mycobacteria). Alternatively, the distance and directional pattern of reported incidence might reflect an odor-induced reporting bias or a "normal" sporadic outbreak of unknown origin. Since many diseases and symptoms were statistically analyzed, it is also quite possible that one or more of the identified statistically significant patterns are "false positives" (i.e., Type I errors).

Other studies of health effects from sewage treatment aerosols tend to corroborate this weak evidence of acute gastrointestinal and skin effects reported near the Egan plant. While most of their investigations of health effects versus exposure were negative, Northrop and coworkers (10) did find some significant correlations of incidence of skin conditions with their index of aerosol exposure at a very large older treatment plant. This association was evident among families whose youngest child was between 5 and 14 and among families with over 20 years of local residence. Rylander and Lundholm have found a high incidence of gastrointestinal symptoms among workers in conventional sewage treatment plants and in a plant composting household garbage and sewage sludge (23). Rylander suggests that endotoxins rather than infectious agents may be responsible for the gastrointestinal symptoms he studied (23-25).

Clinical Specimens. Antibody tests for 31 types of human enteric viruses (enteroviruses, reoviruses, and adenoviruses) resulted in statistically significant rises in titer to Poliovirus 1 and Echovirus 29 and a significant decline in Echovirus 12 titer. The only viral isolates from fecal specimens, picornaviruses, were isolated significantly more frequently after the Egan plant began operation. The subjects with picornavirus isolates had titer rises to a variety of echo and coxsackie viruses, but there was little correlation of the isolates with titer rises or seroconversions. The distance and directional patterns of occurrence suggest that the Poliovirus 1 titer rises and the picornavirus isolates were unrelated to sewage

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Health Effects of Sewage Treatment Aerosols

Sewage treatment and its aerosols have not been found to have obvious adverse effects on health in several extensive studies of American facilities. No clinical or clear subclinical health effects on residential populations were evident, either in this study covering the first nine months of operation of a new activated sludge plant (14) or in Northrop and coworkers' seven-month health watch near a very large older activated sludge plant (10). The health of sewer workers, sewage treatment workers and their families was monitored by Clark et al. in several cities, and no evident adverse health effects of occupational exposure were observed (26). At the exposure levels investigated, the treated sewage and aerosols at well-operated American sewage treatment plants do not appear to be a significant health hazard to the workers or to nearby residential populations.

Infectious or allergic disease effects of lesser consequence, such as the self-reported gastrointestinal syndrome and skin disease in this Egan study, may sometimes occur with greater frequency among nearby residents as a result of moderate exposure to sewage treatment aerosols. The current evidence is insufficient, either to associate or to disassociate such effects with aerosol exposure. The primary difficulty in designing a definitive health watch is the lack of a sufficiently large, sensitive population group (i.e., young children, whose immunologic defenses against infectious diseases are still developing) that resides close enough to the source to receive a high dose of the aerosolized agent(s). Another difficulty occurs in studies of sewage treatment facilities. Interpretation of any observed health effects (especially identifying the route of infection or disease transmission) is confounded by the almost universal practice of locating the sewage treatment plant within the area it services. The ultimate sources of the pathogens in the wastewater aerosol are infected individuals in the service area. If evidence of health effects due to these pathogens were to be found, it is very unlikely that the route of transmission (whether by direct contact, wastewater aerosol, or some other pathway) could be ascertained.

Both of these difficulties in designing a definitive health watch can be partially mitigated by investigating the health effects of wastewater aerosols at new sites where wastewater is applied to land on a large scale by sprinkler irrigation. A demonstration project is being conducted near Lubbock, Texas to construct, operate, and evaluate such a land treatment system. An average of 7.4 mgd (2.8×10^7 l/d) of unchlorinated secondarily treated municipal wastewater from Lubbock will be applied by sprinkler irrigation in a farming community 18 miles away. A three-year prospective infectious disease health watch of the farm families spraying with wastewater and nearby residents and a supporting environmental monitoring program are planned to investigate potential subtle health effects associated with the wastewater aerosol.

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DISCUSSION

MR. LINDAHL: In the City of Des Plaines, when this plant was built, the houses in that area were selling for $40,000 to $50,000 and a distillery was getting about 400 weekly complaints. Today, those same houses are selling for $80,000 to $90,000 and the houses are within 150 feet of the plant fence. So, it would be a good opportunity for you to get some information there. The houses and most of the people living there were there long before the plant was built.

DR. JOHNSON: Well, you are quite right. We know when we went in there that this was a rapidly growing area. They put the plant where there was a convenient place to put it, which was not near people. But that didn't last very long, and certainly by the end of our study, there were a lot of new homes very close to the plant; unfortunately, they were not in our study.

MR. LINDAHL: The present population is about 80,000.

DR. JOHNSON: Thank you.

DR. GERBA: Did the sewage at this plant come from the same community in which the plant was located?

DR. JOHNSON: Primarily, yes. Finding a plant to obtain data before and after operation, in the first place, was very difficult. Trying to find one where they also bring sewage in from a community at a distance is even more difficult.

DR. GERBA: I think your suggestion is very good and will work if you will be taking sewage from large metropolitan areas and putting it in rural areas that are smaller communities. We may really want to study the health effects of that area.

DR. JOHNSON: I agree.

Wastewater Aerosol and School Attendance Monitoring at an Advanced Wastewater Treatment Facility: Durham Plant, Tigard, Oregon

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H. Jac Harding,
Donald E. Johnson

Southwest Research Institute
San Antonio, Texas

ABSTRACT

As the first stage of a potential health hazard investigation, wastewater aerosols and school attendance were monitored at an advanced wastewater treatment plant using the activated sludge process. An elementary school is located next to the new treatment plant. Wastewater aerosols are generated by the aeration basin (within 400 m of the classrooms) and by an aerated surge basin (within 50 m of the school playground).

The aeration basin was observed to be a much stronger source of aerosolized microorganisms than the surge basin. The geometric mean concentrations monitored in air at 30 to 50 m downwind of the aeration basin were 12 cfu/m^3 of total coliforms, 4.2 cfu/m^3 of fecal streptococci, 19 cfu/m^3 of mycobacteria, and 1.5 pfu/m^3 of coliphage. Enteroviruses were not detected in air (<0.0002 pfu/m^3).

After sewage treatment commenced, attendance at the nearby school generally improved, relative both to the baseline school years and to five control schools. The students probably received a peak dose from the aerosol on the order of 2 cfu of mycobacteria and 0.8 cfu of fecal streptococci. At this level of exposure, the sewage treatment aerosol had no adverse effect on communicable disease incidence as discerned from total school absenteeism.

INTRODUCTION

Background

To improve the quality of surface waters, the U.S. Environmental Protection Agency is sponsoring a large program of local construction grants for new wastewater treatment plants. Siting requirements and urban sprawl often dictate that the new wastewater treatment units be located near residential areas.

The Durham Advanced Wastewater Treatment Plant (DAWTP) in Tigard, Oregon, is a modern activated sludge plant funded by the construction grants program that processes 9 to 13 mgd of sewage (3 to 5 × 10^7 l/day). It was built next to the six-classroom Durham Elementary School (DES). The school buildings are located 370 to 470 m from the aeration basin, while the school playground extends to within 50 m of the nearest aerator in one of the surge basins. Local public health officials were concerned that operation of the DAWTP so near the school might facilitate the spread of infectious disease among the school children, especially since "foam blobs" from the aerated surge basin occasionally settled on the playground.

Aeration basins can produce large amounts of wastewater aerosol which may contain many of the pathogenic microorganisms present in the raw sewage. The mechanical aerators used in the surge basin also generate wastewater aerosol. Since these basins are not enclosed, the wastewater aerosol could be carried by the wind into the classroom area and onto the playground. If a sufficient dose were inhaled, the pathogens in the wastewater aerosol might initiate infection in susceptible students.

Two environmental epidemiology studies have recently been performed in the Chicago area, by Northrop and coworkers (1) and by Johnson et al. (2,3) to investigate possible infectious disease effects to populations living near large activated sludge treatment facilities. In both studies, measures of the health of the people living near the plant were compared to those of matched populations living farther away from the plant. Various respiratory and gastrointestinal infectious diseases that might be associated with exposure to aerosols containing microorganisms from the sewage treatment plant were examined via serology, symptom incidence, and isolates from clinical specimens. In general, both studies found little evidence of detectable health effects. This may be because both studies lacked enough sensitive participants who lived sufficiently close to the aeration basins to receive substantial exposure to the wastewater aerosol.

The siting of the DAWTP next to DES was of sufficient public health concern to warrant some investigation. The quality of information to be derived from field monitoring and local school attendance records permitted a cost-effective initial investigation. Depending upon its outcome, a more complete study could then have been made of infectious disease health effects of wastewater aerosols among this population of young children who spent a large portion of their active time (approximately 35 hr/week for 9 months of the year) within a quarter of a mile of an activated sludge plant's aerosol source. The initial investigatory study (4) presented here was conducted to monitor microorganisms in the wastewater aerosols from the DAWTP aeration and surge basins and to evaluate the existing school attendance data.

Study Objectives

The primary objective was to monitor the type and quantity of microorganisms in the wastewater and in the ambient air upwind and up to 100 m downwind of the DAWTP. From these data, an evaluation was to be made of microorganism levels in the wastewater aerosol transported into the school environment.

A secondary objective was to determine whether the absentee rate at DES was significantly different from the absentee rates at control schools located in the same area but not near a wastewater treatment facility. The intent was to provide some preliminary indication of possible health effects which might be associated with the sewage treatment aerosol.

Study Design

The environmental monitoring was performed in two phases. In Phase 1 (November 1977) large samples of wastewater were collected from the two potential sources of aerosolized microorganisms at the plant: the aeration basin and the aerated surge basin. Both wastewater samples were screened to characterize the type and approximate concentration of enteroviruses and a variety of enteric bacteria. The microorganisms to be routinely monitored in the wastewater aerosol during the second phase were then selected. In addition, the relative levels of various test organisms present in the two aerosol sources in the plant were compared in order to determine which source would be the focus of the aerosol sampling.

In Phase 2 (March 1978), six aerosol runs were conducted to simultaneously measure levels of microorganisms in wastewater and air at the aeration basin and the surge basin. A special enterovirus aerosol run was also conducted to measure enterovirus aerosol levels at the aeration basin. The concentration and frequency of microbial aerosols reaching the school were estimated.

Five suitable control schools for DES were selected. Standardized data on quarterly attendance at the six schools were obtained for the seven school years prior to DAWTP operation and for the first two school years of DAWTP operation. If the DAWTP had an adverse health effect, one would expect to see high absenteeism at DES (relative to the control schools) in the two operational years. Such absenteeism might take the form of a uniformly higher absence rate throughout the two operational years, or because of acquired immunity, it might only be evident during the first several months of aerosol exposure episodes.

STUDY SITE

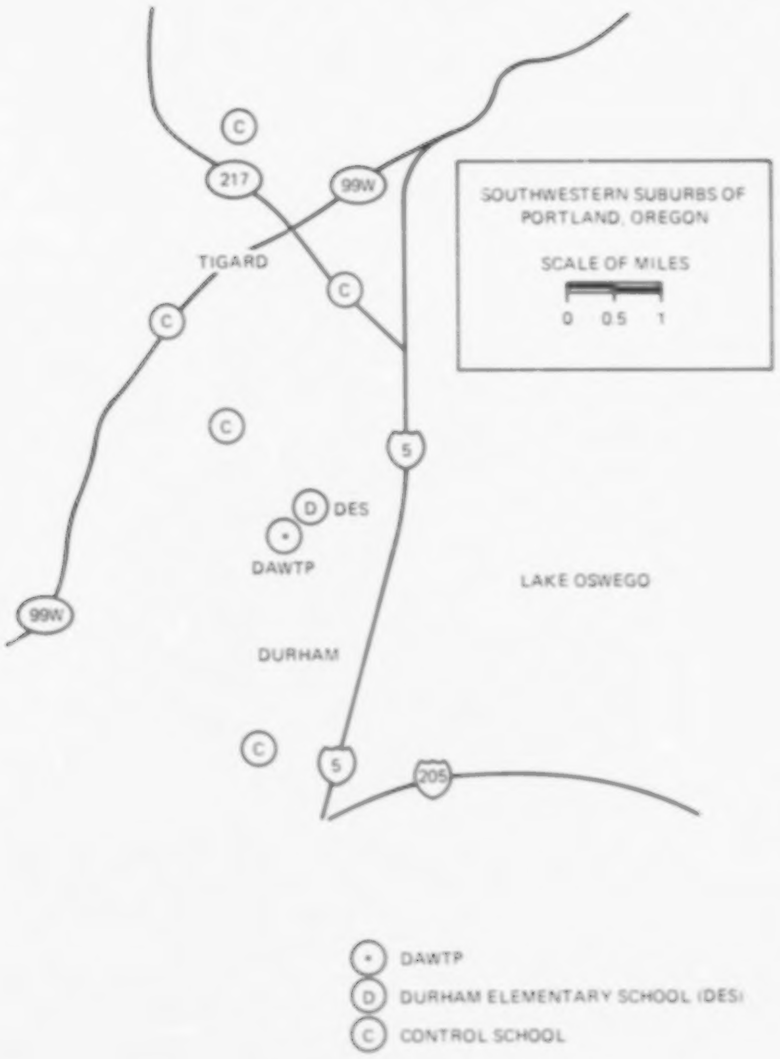
Durham Advanced Wastewater Treatment Plant (DAWTP)

The Durham Advanced Wastewater Treatment Plant (DAWTP) is operated by the Unified Sewerage Agency and serves part of the southwestern suburbs of Portland, Oregon (see Figure 1). The DAWTP is an activated sludge plant with a design capacity of 75,000 m^3/day (20) (see Figure 2).

Treatment Process

The treatment process consists of barminutors to screen out and reduce the size of large objects, primary clarification where settleable solids and grit are removed, and aeration in an aeration basin with activated sludge. These processes are followed by secondary clarification and chemical clarification using alum and coagulant aids to reduce the phosphorus and solids content. The final steps are filtration and chlorination prior to discharge into the Tualatin River. Organic sludge from the primary and secondary clarifiers is processed, heat treated, and incinerated; the resulting ash is used for landfill.

Surge basins of 38,000 m^3 (10 million gallon) and 19,000 m^3 (5 million gallon) capacity accommodate primary clarifier effluent during periods


SOUTHWESTERN SUBURBS OF PORTLAND, OREGON
SCALE OF MILES
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C
5
D DES
DAWTP
LAKE OSWEGO
99W
DURHAM
5
205
DAWTP
D DURHAM ELEMENTARY SCHOOL (DES)
C CONTROL SCHOOL

Figure 1. Study Area

of high flow. Surface aerators are used to prevent the stored wastewater from becoming anaerobic. During periods of low influent flow, wastewater from the surge basins is reintroduced into the treatment process to equalize flow through the secondary and tertiary treatment sections of the plant.

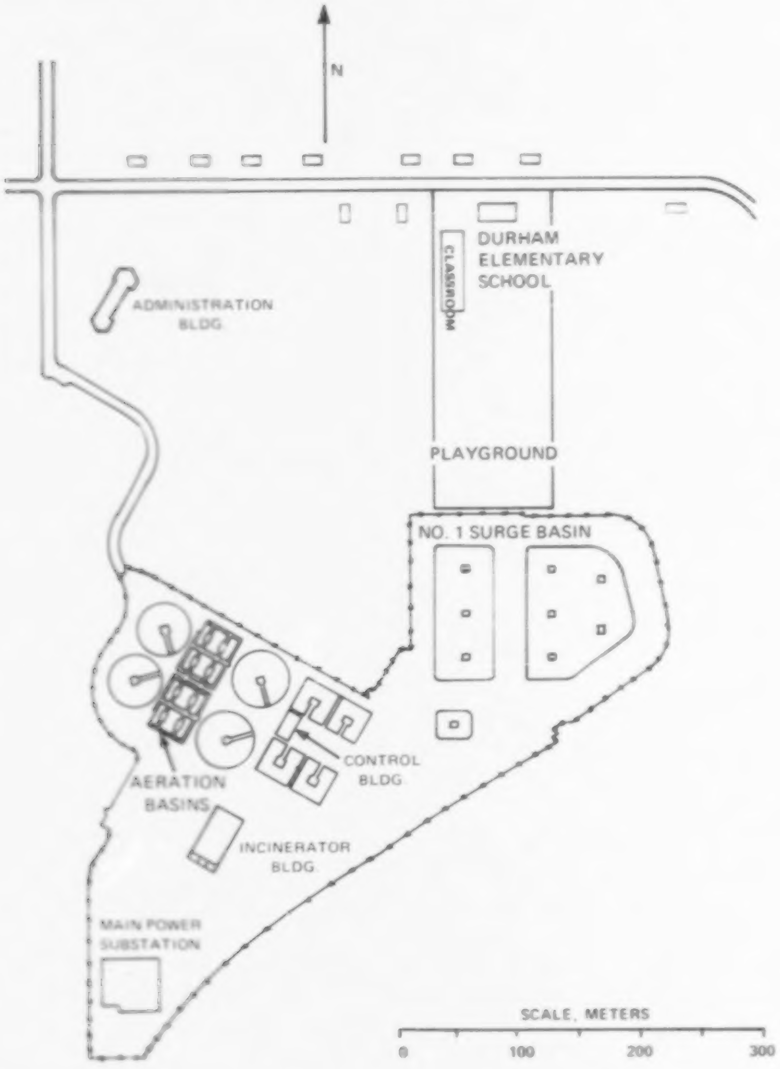

N
DURHAM
ELEMENTARY
SCHOOL
CLASSROOM
ADMINISTRATION
BLDG
PLAYGROUND
NO. 1 SURGE BASIN
AERATION
BASINS
CONTROL
BLDG
INCINERATOR
BLDG
MAIN POWER
SUBSTATION
SCALE, METERS
0
100
200
300

Figure 2. Durham Advanced Wastewater Treatment Plant (DAWTP) and Durham Elementary School (DES)

Microbial Aerosol Sources During Sampling Periods

The aeration basin and the surge basin were determined to be the major sources of microorganism-laden wastewater aerosols. In the 3,800 m^3 (1 million gallon) capacity aeration basin, all wastewater is mixed with activated sludge. Two mechanical turbine mixers agitate the aeration basin liquor and disperse an air stream that is introduced through a 10-cm diameter nozzle oriented vertically upward underneath each turbine at a distance of 1.5m from the bottom of the basin.

The three electro-mechanical surface aerators on the No. 1 surge basin (19,000 m^3 capacity) also produced wastewater aerosol during Phase 2. No wastewater was diverted to or removed from it during the aerosol monitoring.

Study Schools

Durham Elementary School (DES)

The school attendance portion of the study focused on Durham Elementary School (DES), a small six-classroom school (one room for each grade level, one through six) in the Tigard School District which was situated adjacent to the DAWTP. As Figure 2 illustrates, the school buildings are about 370 to 470 m northeast of the DAWTP aeration basin and about 200 m north of the plant's aerated surge basins. Since the school has no air conditioning or forced air circulation, the windows are opened to provide ventilation and cooling during warm weather. The school playground behind the classrooms borders the DAWTP property and extends to within 50 m of an aerator in the closest surge basin.

Year-end enrollment in June 1978 was 123 students. Historically about 60% of the students attend all six grades at Durham Elementary. Nearly all students are white and from families in the middle to upper-middle income bracket, with 40 to 45% residing in apartments. During the timeframe of the attendance study (September 1969 through June 1978), DES had very little teacher turnover. However, new principals were installed in July 1974 and again in July 1976.

Control Elementary Schools

In order to assess the potential health hazard of the DAWTP as reflected in school attendance at the nearby DES, elementary schools not located near the sewage treatment plant were sought for use as controls. The matching criteria employed were racial distribution, socioeconomic status, attendance recording system, and degree of urbanization. Using these criteria, the remaining five elementary schools in the Tigard School District were selected as control schools. The map in Figure 1 shows the general locations of DES and the control schools relative to the DAWTP.

General Characteristics of Schools

Relevant characteristics of the schools are summarized in Table 1. The students attending all the schools were predominantly white, with less than 1% black and Indian and about 1% Oriental. However, DES had a smaller enrollment and served a more rural area than any of the control schools. The socioeconomic status and the proportion of students dwelling in apartments was higher for DES than for some of the control schools.

Table 1. Background Information on Schools in School Attendance Study

Elementary school (grades 1-6)	Distance and direction from Durham plant aeration basins		End of year enrollment (June 1978)	School ventilation system	Students living in apartments	Socio-economic status[a]
	Distance (km)	Direction				
Durham	0.4	NE	123	Open windows[b]	40%-45% (Many)	M-UM
Lewis	3.1	NNE	282	Combination[c]	Many	LM-M
Metzger	5.0	N	426	Combination	Few	L-M
Templeton	1.6	NNW	556	Forced air[d]	Few	M-UM
Tigard	3.0	NNW	648	Combination	Few	L-UM
Tualatin	2.8	S	566	Combination	Many	M-UM

[a] Socioeconomic status categories, based on value of home
L - lower class
LM - lower - middle
M - middle class
UM - upper - middle

[b] Open window - the windows are opened to provide ventilation for cooling and air circulation

[c] Combination - schools having forced air system but often using open windows

[d] Forced air - fans are used to force fresh air through the ventilation system

METHODS AND MATERIALS

Sample Collection

Meteorological Measurements

During the period of aerosol sampling, wind speed and direction, temperature and relative humidity were measured at heights of 2 and 10 m in the vicinity of the aeration basin. Field measurements of solar radiation and cloud cover were also made.

Wastewater Samples

Time-weighed 24-hour composites were collected from the aeration basin and the No. 1 surge basin in Phase 1. Wastewater samples were also collected from these two aerosol sources during each aerosol run.

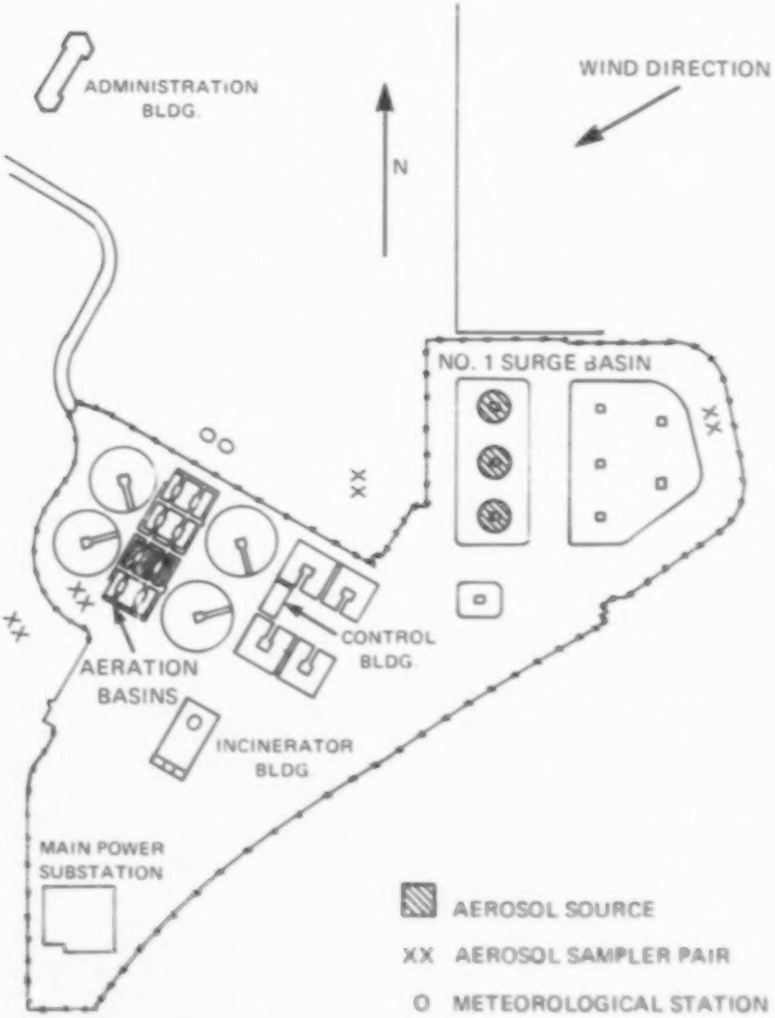
High Volume Air Samples

The Litton Model M large-volume air sampler (LVAS) was used to collect microbial aerosol samples. The sampler collected airborne particles by electrostatic precipitation and concentrated them into a thin, moving film of a liquid medium (brain-heart infusion (BHI) broth with 0.1 percent Tween 80). The LVAS sampled 1.0 m^3/min of air while recirculating the BHI medium at 5 ml/min. Before each aerosol run, the samplers were decontaminated using both absolute ethanol and buffered 1% Chlorox®. The average microorganism collection efficiency of these samplers was 48%.

Air Sampling Protocols

Microbiological Aerosol Runs—

The objective of the microbiological aerosol runs was to simultaneously measure the microorganism levels and their viability decay from the two sources of aerosol: the aeration basin and the No. 1 surge basin. As shown in Figure 3, eight LVAS were deployed in pairs as close as possible to four planned locations (upwind, 50 m downwind of the surge basin, and 30 m and 100 m downwind of the aeration basin) when the wind direction was relatively constant and there was no precipitation. The LVAS were operated simultaneously for 30 min to constitute a microbiological aerosol run. Samples were shipped from the field site to the laboratory for assay within 28 hours after collection.


ADMINISTRATION BLDG.
N
WIND DIRECTION
NO. 1 SURGE BASIN
XX
XX
OO
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XX
AERATION BASINS
CONTROL BLDG.
INCINERATOR BLDG.
MAIN POWER SUBSTATION
▨ AEROSOL SOURCE
XX AEROSOL SAMPLER PAIR
O METEOROLOGICAL STATION

Figure 3. Typical Microbiological Aerosol Run

Enterovirus Aerosol Run—

To provide the necessary sensitivity to detect enteroviruses in the wastewater aerosol, eight LVAS were operated simultaneously in close proximity to each other at 30 m downwind from the aeration basin for nine consecutive 30-min periods. The BHI medium was changed at the end of each 30-min period. At the conclusion of aerosol collection, all the samples were pooled, concentrated in the field, and shipped for assay.

Analytical Methods

Microbial Wastewater Screen

The microbial screen of the wastewater in Phase 1 involved semiquantitative analysis for specific enteric organisms. Both Salmonellae (including Arizona) and *Shigella* were assayed by methods described in Standard Methods (5), which involved concentration by filtration, enrichment, and direct plating on selective media. *Proteus* was determined by directly plating serial dilutions of the sample onto moderately selective and highly selective enteric media. *Staphylococcus aureus* was assayed by spread plating directly to previously solidified plates of mannitol salt agar. Quantitation of *Klebsiella* was determined by employing its ability to produce large mucoid colonies on differential enteric media containing a high concentration of carbohydrate (e.g., eosin methylene blue agar).

Members of the other genera of Enterobacteriaceae (i.e., *Enterobacter, Serratia, Edwardsiella, Escherichia, Citrobacter, Providencia* and *Yersinia*) were determined by picking colonies from samples dilution-plated to moderately selective and highly selective enteric plating media. *Yersinia enterocolitica* was determined by selective enrichment of membrane filter-concentrated samples plated to *Salmonella- Shigella* agar.

Microbiological Assay

Both total coliforms and fecal coliforms were determined by filtration and direct plating on selective media in accordance with Standard Methods (6). After filtration of the sample, fecal streptococci was directly counted after plating on M—*Enterococcus* agar (Difco). Total plate count was determined by serial dilution and direct count. Mycobacteria were assayed quantitatively by a procedure which almost totally suppressed sewage saprophytes while permitting recovery of most mycobacteria. This procedure involved sample processing, selection of colonies, preliminary screen, subculture, and further tests for identification. By using a direct and quantitative approach, fluorescent pseudomonads were assayed by dilution and direct plating on Pseudomonas Agar F (Difco). Coliphage were assayed with *Escherichia coli* K-13 as host in tryptose phosphate agar.

Enterovirus analysis of wastewater samples involved separation into liquid and solid phases, concentration onto bentonite clay and enumeration on HeLa and Buffalo Green Monkey (BGM) monolayers.

Enterovirus Aerosol Sample Assay

The enterovirus study employed a two-stage procedure (field concentration and assay) (7). Field concentration involved classical two-phase polymer separation. Final assay was conducted on the lower phase and interphase from the field concentration volumes utilizing HeLa and BGM monolayers.

Chemical and Physical Analyses

Total organic carbon analyses were conducted on acidified homogenized wastewater samples (6). Total suspended solids and total volatile suspended solids were determined on wastewater sample aliquots (6).

Data Evaluation Methods

School Attendance Data

An accurate and uniform attendance accounting system has been maintained since 1969 for each elementary school in the Tigard School District. The cumulative school attendance data reported to the state for the school years from 1969 to 1970 through 1977 to 1978 were utilized. These data were the total child-days present and absent during each calendar quarter at each school (grades 1 through 6 combined). The percent absent statistic defined as the total days absent divided by total days present and absent was used in the data analysis. To permit a class cohort analysis, these same attendance statistics were obtained for each grade from the local records at DES and the two nearest and socioeconomically similar control schools (Templeton and Tualatin).

Aerosol Exposure

The aerosol exposure of DES students was estimated from a mathematical model of the aerosol monitoring data and from the wind direction readings for each school day, since the school was too distant from the aeration basin for direct aerosol sampling. A rough estimate of the highest dose of aerosolized microorganisms inhaled 1 school day/year was obtained as the product of the highest predicted air concentration during a school day, the student breathing rate, and the duration of exposure.

The estimation procedures for the general form of the microbiological dispersion model when there are two downwind sampler distances (8) were used to compute viability decay rates and predicted downwind air concentrations during each microbiological aerosol run. An index of exposure to aerosols was determined each school day using the 3-hr wind direction readings from the National Weather Service. Based on the number of school days of steady exposure, the percentile corresponding to the highest predicted air concentration at the school distance was selected from the distribution of model predictions during the aerosol runs.

RESULTS

Field Monitoring of Wastewater Aerosol

Microbial Characterization of Wastewater

Results of microbial screens and assays of potential test organisms for large volume wastewater samples collected during Phase 1 from the aeration basin and the surge basin are presented in Table 2. The levels shown for the microbial screen are minimal values since only a portion of the total number of colonies counted on a given media were confirmed. The actual microorganism concentration might have been anywhere from the indicated value to an order of magnitude higher. Mycobacteria and *Klebsiella* levels were fairly high relative to the microbiological indicators, whereas *Salmonella* and *Shigella* were not prevalent.

Table 2. Analysis of Large Samples of Wastewater (Phase 1)

	Aeration basin	Surge basin
Levels of test organisms (cfu/ml)[a]		
Total plate count	4,800,000	210,000
Total coliforms	1,800	1,100
Fecal coliforms	530	160
Fecal Streptococci	67	13
Mycobacteria	13,000	9,700
Pseudomonas	230	100
Coliphage (pfu/ml)[b]	61	<0.2[c]
Enteroviruses (pfu/ml)	0.74	0.009
Microbial screen (semiquantitative cfu/ml)		
Citrobacter sp.	70	30
Enterobacter sp.	500	200
Escherichia coli	70	10
Klebsiella sp.	400	40
Proteus sp.	<30	<3
Providencia sp.	<30	<3[c]
Salmonella sp.	<30	<0.001[c]
Serratia sp.	70	3
Shigella sp.	<0.008	<0.001[c]
Staphylococcus sp.	3	<1[c]
Yersinia	<0.07[c]	<0.02

[a] colony forming units per milliliter
[b] plaque forming units per milliliter
[c] none detected

Monitoring of Wastewater Aerosol

The microorganism groups selected for routine monitoring in Phase 2 based on relative wastewater levels found in Phase 1 were total coliforms, fecal streptococci, mycobacteria, and coliphage. Table 3 shows the mean concentrations of microorganisms as well as of physical and chemical characteristics in the two DAWTP sources of wastewater aerosols during the monitoring in Phase 2. The bacteriological quality of the wastewater in the surge basin was substantially better than that in the aeration basin. Only about 2% of the enteroviruses found in the aeration basin wastewater were in the liquid fraction.

Table 3. Concentrations in the Wastewater During Aerosol Runs

	(Geometric Mean) Aeration basin	 Surge basin
Bacteria (cfu/ml)		
Total coliforms	450,000	44
Fecal Streptococci	4,500	5.3
Mycobacteria	59,000	320
Pseudomonas	1,500	1,200
Viruses (pfu/ml)		
Coliphage	690	0.3
Enteroviruses	0.50	0.002
Physical and chemical characteristics (mg/l)		
Total suspended solids	1,800	100
Total volatile suspended solids	940	44
Dissolved oxygen	1.7	—
Total organic carbon	390	49

Table 4 presents the mean concentrations of microorganisms in the air upwind and at the sampled distances downwind from the aeration and surge basins during the aerosol runs in Phase 2. The microorganism air concentrations tended to decrease with increasing downwind distance from the wastewater aerosol source. The microorganism air concentrations also tended to vary from one aerosol run to another due partially to variations of microorganism levels in the wastewater.

The downwind air concentrations of fecal streptococci and mycobacteria indicate that there were many potentially pathogenic bacteria in the DAWTP aeration basin aerosol and considerable mycobacteria in the surge basin aerosol. The air densities of these potentially pathogenic bacteria were generally as high or higher than the densities of such indicator organisms as total coliforms and coliphage at 70 to 100 m downwind of the aeration basin. Thus, the use of indicator microorganisms such as total coliforms or coliphage in wastewater aerosol monitoring appears to be inadequate to characterize the pathogenicity of the aerosol.

Enterovirus Aerosol Level

No enteroviruses were found 30 m downwind of the DAWTP aeration basin in the total sampled air volume of 1980 m^3. Thus, the enterovirus aerosol concentration was less than 0.002 pfu/m^3 (plaque forming units per cubic meter).

Table 4. Concentrations in the Air During Aerosol Runs

	(Geometric Mean) Downwind of Aerosol Source Aeration Basin 30-50 m	 70-100 m	 Surge Basin 55-95 m	 Upwind (Presumed Background)
Total coliforms (cfu/m^3)	12.2	1.7	0.15	<0.02
Fecal Streptococci (cfu/m^3)	4.2	1.1	<0.02	0.06
Mycobacteria (cfu/m^3)	19.1	4.2	0.32	<0.02
Coliphage (pfu/m^3)	1.5	0.6	<0.04	<0.04
Enteroviruses (pfu/m^3)	<0.002	—	—	—

School Attendance

Annual Comparison

The annual percent absent at DES and the combined control schools are plotted in Figure 4 as two time series. This illustrates that DES historically has tended to have higher levels of absenteeism than the control schools. In the two years after the DAWTP began operation, the absence percentages at DES and the control schools both decreased. During DAWTP operation, attendance at DES improved to a level very close to the attendance at the control schools.

In Table 5, the percent absent in the 2-year operational period is compared to the percent absent in the last 2 years of the baseline period. While a slight decrease in absenteeism occurred at the control schools (−0.32%), DES had a stronger decrease in absenteeism (−0.69%).

If DAWTP operation had had a sustained adverse effect on the health of DES students, an increase might have been anticipated in the absentee rate at DES relative to the control schools in the DAWTP operation years. In contrast, the annual attendance rate at DES improved, both in a simple numerical sense and in relation to control school attendance.

Quarterly Comparison

To examine more transitory health effects, quarterly time series of percent absent at DES and the combined five control schools are presented in Figure 5. There is a pronounced seasonal pattern. The lowest percentage of absences always occurred in the first calendar quarter (September) and the highest absentee percentage usually occurred in the third calendar quarter (January through March). There were no pronounced differences in quarterly absentee percentages between DES and the control schools after the DAWTP began operation.

Class Cohort Comparison

To investigate any patterns obscured in the grouped absentee rates for grades one through six, differences in absenteeism in class cohorts (i.e., children in the same grade level at DES and two similar control schools) were compared using quarterly time series over their years in elementary school. Various DES classes had prolonged periods of higher absenteeism than their control class cohorts, particularly during the baseline. After the DAWTP was operating, there were several periods of slightly higher absenteeism among first and second grade students at DES.

Table 5. Absenteeism Comparison Over Two Year Periods

	Absenteeism (%)		
	Last two baseline years	DAWTP operation years	Operation effect (%)
Durham Elementary	5.36	4.67	−0.69
Control schools	4.96	4.64	−0.32

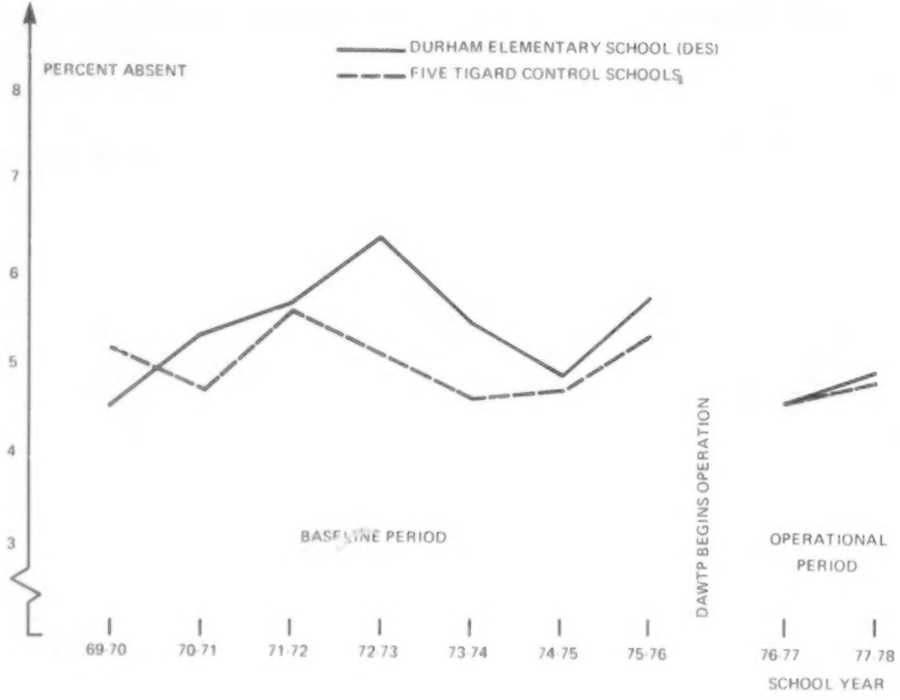

Figure 4. Annual Attendance Plot for DES and the Tigard Control Schools

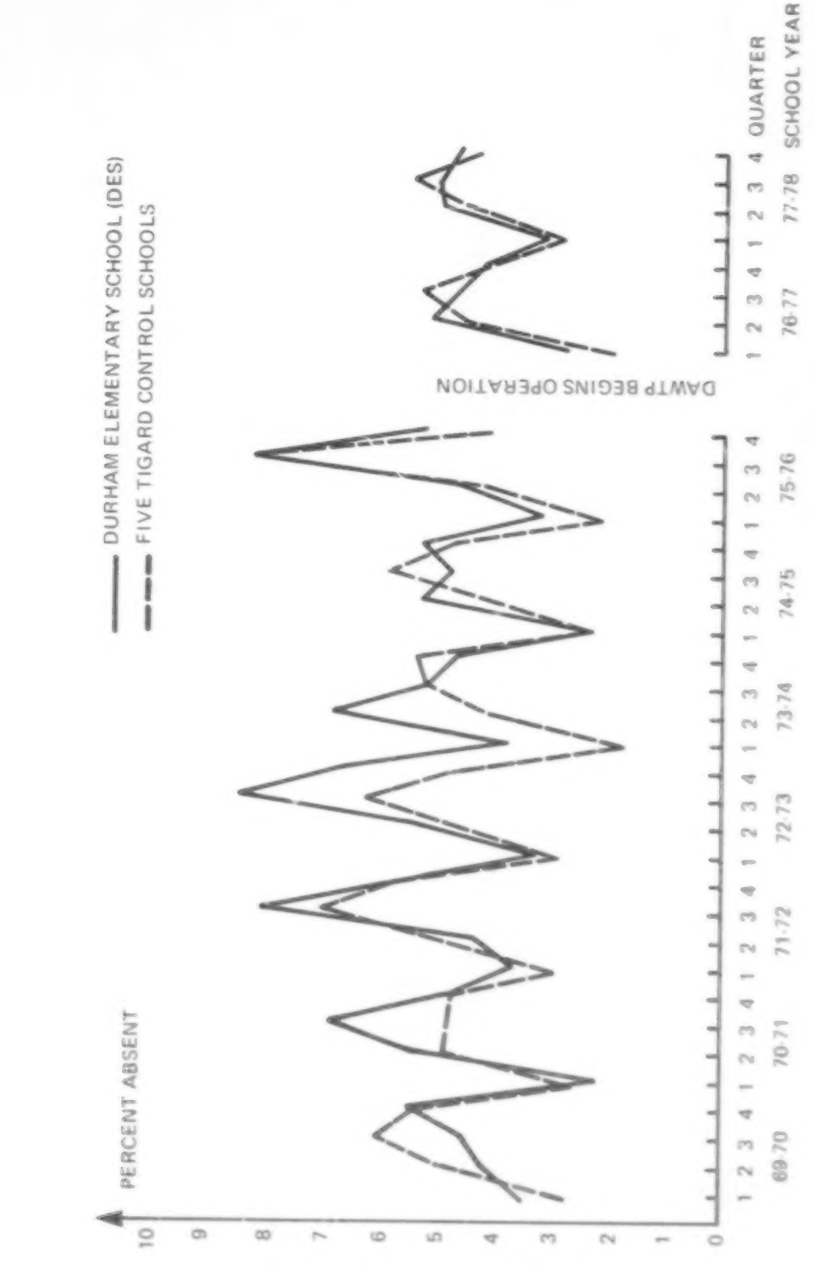

Figure 5. Quarterly Attendance Plot for DES and the Tigard Control Schools

Aerosol Exposure of DES Students

Model Predictions at DES Distance During Aerosol Runs

The rates of viability decay of microorganisms in the aerosol from the DAWTP aeration basin were determined during the six microbiological aerosol runs. The distributions of the viability decay rates are presented in Table 6. With so few runs, no significant difference in viability decay rates could be detected for the DAWTP aeration basin aerosol in comparison to a thoroughly monitored sprinkler irrigation aerosol (9).

Model predictions were made of the microorganism concentrations in air at the school distance (450 m) on the centerline downwind from the aeration basin during each aerosol run. There are probably one or more magnitudes of uncertainty in each model prediction of the air concentration at such a large downwind distance (8,4). The distributions of the model predictions for fecal streptococci and mycobacteria are presented in Table 7. They are also contrasted in Table 7 with the background outdoor concentrations estimated from the upwind air samples. It appears that the aeration basin aerosol appreciably increases the air concentration of fecal streptococci and mycobacteria above the background levels normally inhaled by the students. This occurs about half of the time that the DES classrooms are downwind of the DAWTP aeration basin.

Table 6. Estimates of Viability Decay Rate λ From DAWTP Aeration Basin

	Distribution of λ (sec^{-1}) values			
Percentile	Total coliforms	Fecal Streptococci	Mycobacteria	Coliphage
25	−0.059	−0.051	−0.057	−0.054
50	−0.043	−0.027	−0.041	[a]
75	−0.035	[a]	[a]	[a]

[a] Indeterminate viability decay rate; for model calculations, [a] may be presumed to represent λ = 0.0 sec^{-1}

Table 7. Model-predicted Air Concentrations At School Distance from DAWTP Aeration Basin

	Distribution of Model-predicted concentrations P_{450}(cfu/m^3) at 450 m from aeration basin	
Percentile	Fecal Streptococci	Mycobacteria
25	4×10^{-6}	4×10^{-6}
50	6×10^{-4}	8×10^{-5}
75	0.17	0.40
83	0.42	0.92
Estimated Background	0.06	<0.02

Frequency and Persistence of Aerosol Exposure at DES

The distribution of the exposure of DES students to DAWTP aerosols is presented in Table 8. The classroom area was steadily downwind of the aeration basin on only 10 school days in the 2 operational years. All of these days were rainy, cloudy, cool, and humid (i.e., conditions conducive to survival of aerosolized microorganisms between the showers). Because of rainfall, the DES students may have used their playground on only about 40% of the days when it was steadily exposed to aerosols. The first school days on which the playground received steady exposure to the surge basin aerosol were in December 1976. The classroom area was not steadily exposed until February 1977.

Estimated Maximum Inhaled Dose of Aerosolized Microorganisms

The calculation of the highest dose of aerosolized microorganisms likely to be inhaled during one school day per year is presented in Table 9. Considering the assumptions and data extrapolations involved, each dose estimate could well be a factor of 10 higher or lower than the value calculated in Table 9.

The highest inhaled doses received one school day per year, both in the classroom and on the playground, were probably on the order of 0.8 cfu (colony forming units) of fecal streptococci and 2 cfu of mycobacteria. The majority of the peak school day dose was probably inhaled in the classroom area. The peak inhaled dose of about 0.8 cfu/day of fecal streptococci from the DAWTP aerosol is not much larger than the estimated usual background dose (about 0.13 cfu/day) from other sources in the school area. However, the peak inhaled dose of about 2 cfu/day of mycobacteria from the aerosol appears to be larger than the usual background dose of mycobacteria.

DISCUSSION

The aeration basin was observed to be a much stronger source of aerosolized microorganisms than the surge basin. The geometric mean aerosol concentrations at 30 to 50 m downwind of the aeration basin were 12 cfu/m^3 of total coliforms, 4.2 cfu/m^3 of fecal streptococci, 19 cfu/m^3 of mycobacteria, 1.5 pfu/m^3 of coliphage, and <0.002 pfu/m^3 of enteroviruses. Aerosolized mycobacteria were found to be more prevalent at this plant than at previously monitored sites (9,3). The inability to detect enteroviruses in air resulted from their low concentration (relative to other test organisms) in the wastewater and from their absorption onto and incorporation into the mixed liquor suspended solids which are not easily aerosolized.

After the DAWTP began sewage treatment, overall attendance at DES actually improved, relative both to baseline attendance at DES and to attendance at the five control schools. Although school absenteeism may reflect many factors besides illness, it can be an efficient measure of infectious disease incidence when such other major confounding factors as socioeconomic status and annual weather differences are properly controlled (10). Thus, DAWTP operation had no discernible adverse

Table 8. Frequency and Persistence of DES Student Exposure by Calendar Quarter

School day exposure index	Number of school days									Percent of school days
	1976-77				1977-78				Both school years	
	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q		
Exposure of classroom area to aeration basin aerosol										
0 (None)	11	30	30	25	6	27	42	25	196	55
1-2 (Occasional)	6	17	14	9	6	12	8	11	83	23
3-4	1	5	5	9	4	7	5	7	43	12
5-6	0	2	5	5	3	3	1	4	23	6
7-8 (Steady)	0	0	4	0	0	5	0	1	10	3
Exposure of playground area to surge basin aerosol										
0 (None)	11	24	18	23	6	15	19	21	137	39
1-2 (Occasional)	5	17	20	9	5	12	17	11	96	27
3-4	2	5	7	7	3	13	14	9	60	17
5-6	0	5	5	7	2	7	5	4	35	10
7-8 (Steady)	0	3	8	2	3	7	1	3	27	8

effect on the incidence of communicable illness as reflected by total school absenteeism. The slight improvement in DES attendance may have been produced by some unrecognized factor. One possible explanation is the change in principal coincident with initial DAWTP operation (i.e., the young new principal was observed to interact closely and positively with the students of his small school).

Table 9. Estimated Maximum Daily Dose of Aerosolized Microorganisms Inhaled by Students at DES

	Highest expected dose per year from DAWTP			Usual background dose "Normal outdoors"
	From aeration basin		From surge basin	
	In classroom area	At playground	At playground	
Distance from aerosol source	450 m	300m	50	—
School days per year of steady Exposure (from Table 8)	5	3^a	5^a	177
Percentile of highest day	83%	75%	83%	—
Estimated mean air concentration on highest day (cfu/m^3)				
Fecal Streptococci	0.42^b	0.36^b	<0.15^b	0.06^b
Mycobacteria	0.92^b	0.88^b	0.90^b	<0.02^b
Student breathing rate (m^3/hr)	0.25^c	0.43^c	0.43^c	0.27^c
Duration of exposure (hr/day)	7	1	1	8
Estimated dose inhaled on highest day (cfu/day)				
Fecal Streptococci	0.74^d	0.15^d	<0.06^d	0.13^d
Mycobacteria	1.6^d	0.38^d	0.39^d	<0.04^d

[a] Excluding days playground not usable due to rain

[b] Assumes conditions sampled during one week monitoring period reflect both the levels and variability encountered in first two years of DAWTP operation

[c] Assumes an average child body surface area of 1.0 m^2, an at-rest breathing rate of 3.6 l/min/m^2, a classroom rate 15% above at-rest, and playground rate twice the at-rest rate

[d] Estimated inhaled dose = Air concentration × breathing rate × exposure duration. Each dose estimate is subject to at least an order of magnitude of uncertainty.

The DES students may have received added exposure through DAWTP aerosols to such potential pathogens as mycobacteria and fecal streptococci on perhaps 10% of the school days after the DAWTP began operation. The peak doses inhaled from the aerosol about 1 school day/year were probably on the order of 2 cfu of mycobacteria and 0.8 cfu of fecal streptococci.

While DAWTP operation has had no discernible adverse effect on communicable disease incidence, continued limited health monitoring of the DES students appears to be warranted. Several periods of increased absenteeism of dubious significance were observed among first and second grade students at DES after the DAWTP began operation. Continued surveillance of school attendance, especially among the younger children, should be maintained for DES and the control schools beyond the 1977-78 school year to determine if this is a recurring pattern.

ACKNOWLEDGEMENT

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DISCUSSION

SPEAKER: I want to ask you, Mr. Camann, why are these treatment plants being built? Where was the sewage going before it was going to the sewage treatment plant?

MR. CAMANN: Well, at the Durham site there were a number of small sewage treatment plants throughout this area. The service area is now served by this modern plant, and sewage was consolidated into this one plant to improve the effluent characteristics and improve the Tualatin River, into which the wastes were dumped.

MR. SAWYER: I've got a couple of questions relating to the source strength. Am I to conclude that you are saying that it is not possible to directly determine the source strength from aeration basin strength?

MR. CAMANN: I have not ever seen such a calculation done because you cannot calculate the diffusion pattern very close to the source. So the best thing to do is to take an aerosol sample close enough downwind where decay has not been a major factor and yet where the diffusion has gotten into a stable pattern, so that you can diffusion model it. That is the approach that I have seen done in other places and that is the approach I took.

MR. SAWYER: The second thing is that on one of the slides that you showed, I don't remember the exact number, but I think it was something like 92.3 cfu/m^3. When you do a mathematical model, and your Q represents source strength, that term has to be defined in terms of an emission rate per unit time, and not in terms of the concentration factor, which is what you gave. Even using your back calculation, can you say what is the emission rate from those factors?

MR. CAMANN: I was not interested in trying to do the calculation. I really could not tell you offhand. I would have to look at it.

MR. SAWYER: Do you think it would be possible to get those kinds of terms from your data?

MR. CAMANN: I am not positive that I've got all the relevant information which might be required. I know that we did not do it to the extent of diffusion modeling at this site because it was expensive and this was a limited study. I think it would be possible to do the back calculation from our aerosol values. It would be a fairly extensive time-consuming operation and beyond the scope of this monitoring approach.

DR. SORBER: To help answer that particular question you could get this emission rate if you had an estimate of impact factors of that aeration basin, which is difficult to do in modeling. You are assuming the combination of emission rate and impact factor at the close in location.

MR. CAMANN: Right. The Q would take into account both things and would not be able to distinguish among various parts of it.

DR. SORBER: That's right. There is no way we could do that at this particular site and to identify the impact factors separately. We haven't been able to do that. We can calculate the rate per square foot.

Health Effects of Aerosols Emitted from an Activated Sludge Plant

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ABSTRACT

An 8-month environmental health study was carried out in a 1.6 km area surrounding a 202 mgd activated sludge plant. A cross-sectional demographic and health survey of a random sample of persons residing within the study area revealed that they were relatively homogeneous, predominately white, upper middle class, and with no remarkable prevalence of health problems. Seven hundred and twenty-four people (246 families) volunteered to record self-reported illnesses at biweekly intervals. Throat and stool specimens were collected from a selected subsample of 161 persons providing a total of 1,298 specimens analyzed for pathogenic bacteria and viruses. Three hundred and eighteen persons submitted paired blood samples at the beginning and end of the study period to determine prevalence and incidence of infections to five-coxsackie- and four-echovirus types. No remarkable correlations were found between the exposure indices and rate of self-reported illnesses or of bacterial or viral infection rates determined by laboratory analysis. However, the plant was identified as a source of viable particles and total coliforms. The overall conclusion that this activated-sludge treatment plant had no obvious adverse health effect on residents potentially exposed to aerosol emissions must be tempered by the very small number of people who were exposed to the highest pollution levels. This plant was not a source of high concentrations of viable particles, gases, or metals, and the plant levels of the aerosolized pollutants were much lower than those reported by other investigators for similar plants.

Objectives of Study

This study was designed to determine whether or not the health of persons exposed to aerosols emitted by a sewage treatment plant is significantly different from that of persons living in less exposed areas around the plant site. Field and laboratory studies to evaluate the environmental and health status include:

- assessment of microorganisms and metal and gaseous constituents in sewage with emphasis on those components considered to be hazardous to human health
- assessment of the quality, quantity, and distribution of viable particles, nonviable particles, and gases in the air originating from the sewage treatment plant and in the community
- assessment of the health, particularly with reference to infectious diseases, of persons living in areas exposed to different concentrations of viable and nonviable pollutants originating from the plant

- interrelating the above data to determine the potential and actual health hazard of exposure to sewage aerosols.

Scope of Work

In an attempt to determine whether or not the sewage treatment plant was hazardous to the health of the community exposed to the plant aerosols, several measurements of health were made.

First, a retrospective questionnaire survey of the types of diseases, particularly of infectious character, was conducted on these diseases that had occurred in the previous 12 months.

Second, a Health Watch, which was a prospective study of self-reported illnesses by the sample population as well as microbiological studies of throat and fecal specimen cultures, was conducted. Biweekly diaries of self-reported infectious-like diseases and biweekly throat and/or fecal specimens of members of selected households were collected by field staff for 8 months. Also, two blood samples were collected from this study group, one at the onset of the study and the second 8 months later. The serosurvey provided both prevalence data of certain types of infectious diseases encountered in the past and incidence of those encountered during the study period.

The analysis and interpretation of the health information collected was based on the biometric and epidemiological concept of a dose-response relationship; i.e., persons living in areas more highly exposed to aerosols originating at the plant site may have different frequencies or types of health problems than persons living in low exposure areas. Accordingly, a separate control population group was not needed. Conceptually, if the sewage treatment plant was the source of infectious agents, trace metals, gases, or other hazardous materials, then the level of exposure may be directly related to the number of infections and/or diseases occurring in the exposed population.

Sewage and air monitoring programs were conducted to characterize the type and extent of exposure of populations living within the study area to pollutants emitted by the plant. The air pollutants monitored included three general categories: viable particles, nonviable particles, and gases. In addition, these substances were monitored in the sewage at different stages of treatment.

The environmental measurement program characterized, through 8 months of monitoring, the exposure of individuals living in the vicinity of the plant. This was accomplished by generating models of air concentrations within the study area for each pollutant measured. These concentrations were used to develop a personal exposure index for each participant, and these indices were the basis for comparative health analysis. In addition, through use of these measurements, an attempt was made to relate the dispersion of pollutants to appropriate meterological parameters and to a plant operation data model. This model would attempt to predict air concentrations of each pollutant at various distances from the plant based on such factors as wastewater aeration rate, wind speed and direction, concentration of pollutant in wastewater, and solar radiation.

All health data obtained from the questionnaire, the Health Watch, and the corresponding laboratory results were recorded into a personal health file for each person interviewed and/or participant in the study. These personal health files were referenced according to an individual and household identification number. Incidence rates of various illness categories were obtained for each person and/or household. A pollution exposure index was available for each person or household. From these data sets, a dose-response relationship between different levels of exposure to sewage plant emissions and illness and infection rates was investigated.

Standard techniques such as regression and analysis of variance were used to relate the health and environmental data.

Description of Plant

The sewage treatment plant, referred to as the North Side Sewage Treatment Works (NSSTW), used in this study is located in Skokie, Illinois.

The NSSTW is an activated sludge plant employing diffused aeration with a little tapered aeration. Chlorination occurs after the final settling process. No sludge processing occurs at the plant. The maximum capacity of the plant is 1.51×10^9 l of raw sewage/day. During the study period (April to November 1977) the plant had an average daily flow rate of 1.1×10^9 l of sewage and a median air rate of 4.6×10^6 m^3/day. The estimated surface area of sewage in the aeration tanks is about 55,000 m^2 in settling tanks, concentration tanks, etc., exposed to the atmosphere. The total retention volume of one battery of aeration tanks is 7.45×10^4 m^3. The tank levels were maintained at approximately 4.6 m. Residence time of sewage in the aeration tanks is generally $5^1/_4$ hours.

Description of Study Area

The area within a 1.6 km radius of the treatment plant as shown in Figure 1 was designated as the study area. Previous studies suggested that the dispersion of viable particles does not exceed 0.8 km from a source. Therefore, the 1.6 km radius study area permitted analysis of exposed and unexposed populations. As can be seen in Figure 1, the plant is located in a small industrial area which occupies most of the land within the first 0.4 km ($^1/_4$-mile) radius of the plant. The major residential section begins at the 0.4 km radius line and extends uniformly through the 1.6 km radius area. The population of the study area was estimated to be 15,850 persons, or 5,600 households, based on the 1970 census.

HEALTH ASSESSMENT PROGRAM

Methods

Sampling

In order to obtain a sample of households that would be distributed throughout the study area, three concentric sampling zones were designated around the sewage treatment plant as shown in Figure 2.

Since the number of residences in the first 0.8 km radius was small (394) compared to the next two 0.4 km radius areas (1,308 and 3,630, respectively), a random sample of the entire area would have provided many more households in the outer 0.8 km area. Therefore, a random sample was chosen for each zone in order to obtain a more uniform

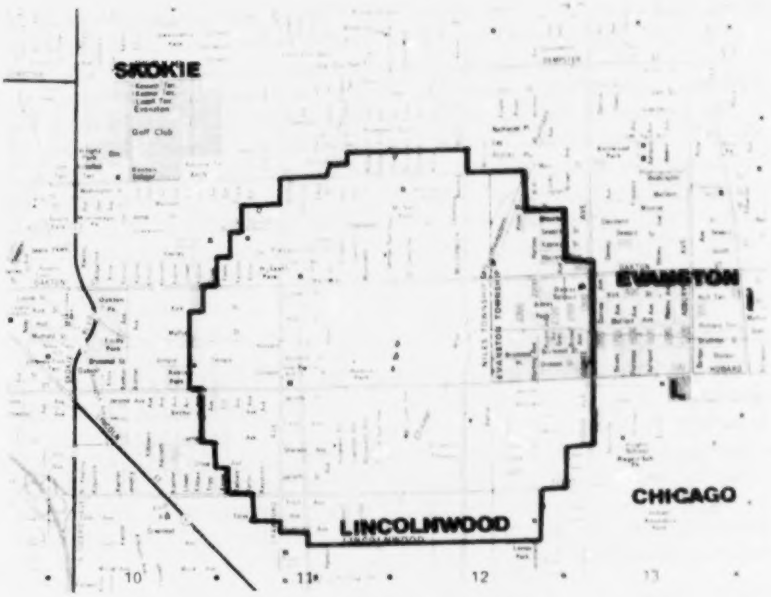

SKOKIE
Golf Club
EVANSTON
CHICAGO
LINCOLNWOOD
NILES TOWNSHIP
EVANSTON TOWNSHIP
10
11
12
13

Figure 1. Map of Study Area

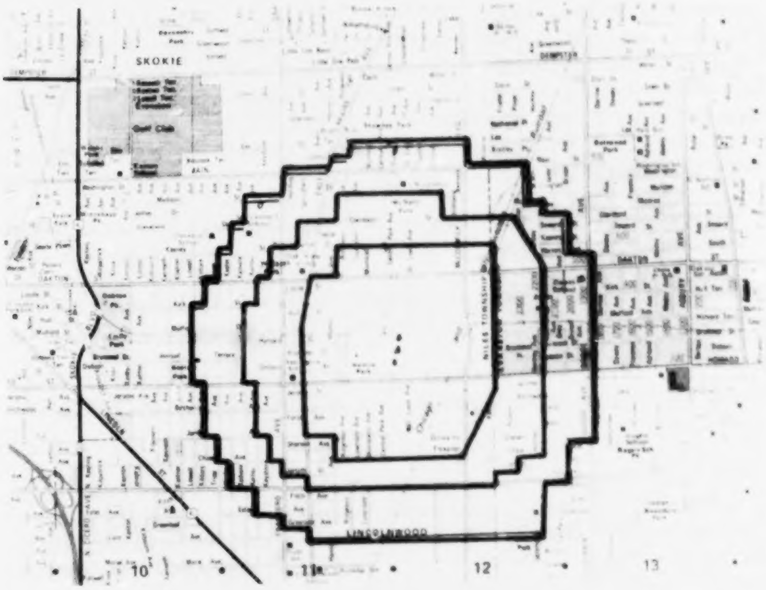

SKOKIE
Golf Club
DEMPSTER
OAKTON
NILES TOWNSHIP
LINCOLNWOOD
10
11
12
13

Figure 2. Map of Sampling Zones

geographic distribution of households throughout the study area. It is emphasized that these zones were established for sampling purposes only. Final data analyses were based on actual viable and nonviable pollution exposure levels, and not geographic distances.

The sample design was a disproportionate stratified sample with the three sampling zones forming the strata. Since an equal number of households was required per zone, the sample size for each zone was determined by the number of households in the smallest zone, sampling zone 1. Only 394 households were present in sampling zone 1; thus, nearly every family in sampling zone 1 was included in the sample and an equal number of households was then selected in sampling zones 2 and 3.

Health Questionnaire

The survey instrument was a 34-page booklet containing 29 questions and required approximately 45 minutes of interview time for an average family to complete. Questions were asked by trained interviewers regarding demographic, historical health, occupational, and living conditions for each member of the family. Usually each member responded for himself. Certain families fulfilling the requirements to be a Health Watch participant were recruited at the time of the health questionnaire interview into the Health Watch.

Health Watch

In order to obtain ongoing, prospective information about health in the study population, a subsample of the persons interviewed in the health questionnaire survey was solicited into the Health Watch. Participants, as family units, were asked first to maintain a health diary to self-report any and all illnesses they encountered for an 8-month period. Secondly, they were requested to provide blood samples at the beginning and again at the end of the 8-month period. Finally, certain families were asked to provide clinical specimens for biweekly microbiological surveillance as follows:

- When children 12 years or younger were present, then biweekly throat and stool specimens were requested from the children. In addition, the next older person over 12 years of age in those households was requested to provide only a stool specimen biweekly. All persons over 6 years of age were asked to give two blood samples as well as to maintain the diary.
- If all persons in the household were over 12 years of age, two blood samples and diary maintenance were requested from each household member.

The study design and sampling for the Health Watch were extensions of the design and sampling methods described for the health questionnaire survey. Specifically, 290 households were needed to participate in the Health Watch in order to have sufficient health-related data for analysis. Each diary provided directions and space for self-reporting of any illnesses that occurred in a 2-week period. The information requested included:

- date illness began
- person in family experiencing illness
- nature of illness and/or symptoms
- number of days ill with no restriction of activity
- number of days of restricted activity
- medications taken
- physician consulted
- hospitalization
- date of recovery.

Results and Discussion

Health Questionnaire Survey

Demographics of Survey Population. The 807 households (2,378 individuals) participating in the health questionnaire survey were distributed throughout the 1.6 km radius study area as shown in Table 1. It can be seen that the households were nearly equally distributed with regard to distance from the plant. Since the main health variable to be considered was the incidence of infectious diseases relative to air quality, it was important to determine that the study population in each area was composed of persons with similar demographic characteristics. Age, sex, race, socioeconomic status, and family size are known confounding variables in the incidence of many infectious diseases.

Overall, the families participating in the health questionnaire survey, regardless of their residence location in the study area, were characterized as white (93.6%), middle class ($22,317 median income), white collar workers (76.8%), with an average family size of 2.9 people, and were a stable population having lived in the study area for more than a decade (mean = 11.7 years).

The analyses of the general characteristics of the subsets of the health questionnaire survey population according to location of residence in the study area have shown that there are minor significant differences in these subsets. Age, race, family size, length of residence, and occupation were significantly different; whereas sex, income, and home air conditioning were not. The differences, although minor, were incorporated into later interpretation of the health data.

Prevalence of Chronic Conditions in the Survey Population. The concern about chronic conditions in the study population was twofold: first, a number of chronic conditons have been associated with metals, gases,

Table 1. Distribution of Health Questionnaire Survey Population by Distance of Residence from Plant

Distance of residence from plant (km)	Households		Individuals	
	No.	%	No.	%
0.0-0.8	269	33.3	847	35.6
0.8-1.2	267	33.1	791	33.2
1.2-1.6	271	33.6	740	31.1
Total	807	100.0	2,378	100.0

or infectious agents that are present in the environment; and second, individuals with chronic illness may be at a higher risk to acute infectious diseases than those without such conditions. Table 2 lists the chronic conditions specifically inquired about in the questionnaire and the corresponding number of conditions per 100 persons in the residential areas. For the 2,378 respondents, 2,006 chronic conditions were reported. The rates for respiratory conditions (26.6/100), cardiovascular (20.4/100), gastrointestinal conditions (21.1/100), and other chronic conditions (28.0/100) combined for an overall prevalence of 96.6 conditions/100 persons interviewed. It was not possible to assess these rates because they represent self-reported conditions experienced in the lifetime of the survey participants; comparable data have not been reported in the literature.

No association was found (one-way analysis of variance, p> 0.05) between the prevalence of chronic respiratory, chronic cardiovascular, or all chronic conditions and distance of residence from the plant. However, a significant difference (one-way analysis of variance, p< 0.01, followed by Duncan multiple range test) was observed between the prevalence of chronic gastrointestinal conditions in the 0.0 to 0.8 km and 1.2 to 1.6 km residence groups; persons living farthest from the plant had more gastrointestinal conditions than those living nearest the plant site. The 1.2 to 1.6 km residence area had a higher percentage of persons over 59 years old (26.1%) than the other two residence areas (14.3 and 19.7%) which may be a possible explanation for the above observation.

Table 2. Average Number of Reported Chronic Conditions/100 Persons by Distance from Plant

Type of chronic condition	Distance of residence from plant (km)			
	0.0-0.8	0.8-1.2	1.2-1.6	Total
Respiratory conditions[a]	25.3	29.2	25.3	26.6
Cardiovascular conditions[a]	18.4	21.2	21.9	20.4
Gastrointestinal conditions[a]	17.0	21.6	25.3[b]	21.1
Other cancers	2.1	2.6	3.6	2.7
Arthritis	9.9	9.6	11.5	10.3
Infectious hepatitis	1.0	1.2	1.4	1.2
Diabetes	4.4	5.1	3.2	4.2
Anemia	3.7	2.7	4.1	3.4
Other chronic conditions	6.6	6.1	5.9	6.2
Total	76.5	87.2	90.3	84.3

[a] Includes cancers

[b] Significantly greater (one-way analysis of variance test, $p < 0.05$, in conjunction with Duncan multiple range test) than that for 0.0-0.8 km residence group

Acute Illnesses Reported for Year Prior to Interview. Table 3 contains a summary of the rate of acute illnesses/1,000 person-days for the year prior to the onset of the study. The average rate of 1.64 illnesses/1,000 person-days was likely an underreporting since recall of short-term illness is probably unreliable, particularly if one family member responds for other family members. This was borne out by several surveys over the past few decades where the average experience was 2.5 to 4.4 illnesses/1,000 person-days.

Table 3. Average Number of Acute Illnesses/1,000 Person-days During Months Prior to Survey by Distance from Plant

Distance of residence from plant (km)	Type of acute illness				
	Respiratory	Gastrointestinal	Eye/ear	Skin	Total
0.0-0.8	0.96	0.30	0.19	0.25	1.70
0.8-1.2	0.90	0.22	0.11	0.19	1.48
1.2-1.6	0.93	0.38[a]	0.14	0.27	1.75
Total	0.93	0.30	0.16	0.25	1.64

[a] Significantly greater (one-way analysis of variance test, $p < 0.05$, in conjunction with Duncan multiple range test) than that for 0.0-0.8 km residence group

Health Watch

Demographic Comparisons. Of the 807 households that participated in the health questionnaire survey, 290 households (869 individuals) became participants in the Health Watch to determine the incidence of health problems prospectively over an 8-month period. The remaining 517 households (1,509 individuals) were designated as "questionnaire-only" households. A demographic comparison (age, sex, race, family size, and income) of these two subsamples was made to determine whether the Health Watch participants adequately represented the entire questionnaire population (n = 807 households), and the demographic distributions were found to be similar for the two subsamples.

During recruitment of households for the Health Watch, 61 households (162 individuals) refused to participate in the study. In order to maintain the original sample size, the refusals were replaced with 54 alternate volunteer households (163 individuals). The Health Watch refusals were demographically similar to their replacements.

Of the 290 households that participated in the Health Watch, 44 (15%) dropped out during the course of the study (see Table 4). The 246 families completing the Health Watch included 724 individuals; the 44 dropout families consisted of 145 individuals. Health Watch families dropping out of the study were demographically similar to those completing

Table 4. Summary of Health Watch Participation and Completion[a]: April 3–November 26, 1977

Distance of residence from plant (km)	Number entering Health Watch		Number completing Health Watch			
	Families	Persons	Families		Persons	
			No.	%	No.	%
0.0-0.8	95	306	82	86.3	252	82.4
0.8-1.2	93	289	80	86.0	245	84.8
1.2-1.6	102	274	84	82.3	227	82.8
Total	290	869	246	84.8	724	83.3

[a] Based on diary participation.

the study. The demographic characteristics of the drop-outs and those who completed the Health Watch are presented in Table 5.

Table 5. Demographic Profile of Health Watch Participants

Individuals			Households		
Age (years)	No.	%	Family size	No.	%
<6	32	3.7	1	28	9.7
6-18	162	18.6	2	107	36.9
19-59	473	54.5	3	56	19.3
>59	202	23.3	4	62	21.4
Total	869		5	21	7.2
Mean age = 39.7			≥6	16	5.5
			Mean family size = 3.00		
Sex	No.	%	Income (× $1,000)	No.	%
Male	411	47.3	<10	24	8.3
Female	458	23.3	10-14.9	29	10.0
			15-24.9	79	27.2
			≥25	104	35.9
			No answer	54	18.6
			Median income = $23,200		
			Race	No.	%
			White	270	93.1
			Other	20	6.9

Health Diary Data. The distribution of the types and number of illnesses reported and of the person-days observed during the 17 biweekly periods of the study are shown in Table 6.

Table 6. Distribution of Reported Illnesses and Exposure Days by Data-Collection Period

		No. of illnesses					
Beginning date of 2-week data-collection period, 1977	No. of person-days of exposure[a]	Respiratory	Gastro-intestinal	Eye-ear	Skin	All other[b]	Total
April 3	3,486	20	9	2	3	5	39
April 17	5,794	40	9	6	5	7	67
May 1	10,062	73	15	13	2	7	110
May 15	10,504	65	21	14	3	5	108
May 29	10,231	49	14	8	6	10	87
June 12	9,858	54	19	5	2	4	84
June 26	9,496	25	10	5	2	3	45
July 10	9,398	37	19	10	3	9	78
July 24	9,162	56	18	15	3	3	95
August 7	9,331	64	11	6	7	9	97
August 21	9,423	61	16	9	2	6	94
September 4	9,604	69	21	4	6	4	104
September 18	9,465	82	14	8	5	5	114
October 2	9,425	108	17	7	6	6	144
October 16	9,166	65	25	1	4	5	100
October 30	9,262	59	16	2	4	2	83
November 13	9,359	91	21	3	3	5	123
Total (%)	153,026	1,018 (64.8)	275 (17.5)	118 (7.5)	66 (4.2)	95 (6.0)	1,572 (100.0)

[a] Total number of days all persons participating in Health Watch were present in the study area during the data-collection period

[b] Includes other acute infections, exacerbations of chronic conditions and new chronic conditions

From these data, illness rates were expressed as follows:

$$\frac{\text{number of illnesses}}{\text{number of person-days observed}} \times 1{,}000 = \text{illness rate/1,000 person-days.} \qquad \text{(Equation 1)}$$

Thus, the total number of 1,572 illnesses reported during 153,026 person-days observed equaled a rate of 10.27 illnesses per 1,000 person-days as shown in Table 7. In general, these illness rates were consistent with the Health Interview Survey (HIS) for 1975 to 1976 reported by the National Center for Health Statistics (NCHS). The rates shown in Table 7 were nearly 1.7 times higher than those reported by NCHS. This study and the HIS were not conducted in the same way and cannot be directly compared. It is possible that the Health Watch participants were more health conscious than the general population because there was some degree of self-selection on the part of the Health Watch families, even though they were demographically similar to a random sample of the study area population. The outcome of a self-selected, health-conscious group would tend to result in overreporting of illness. It is also emphasized that illness is defined here as any deviation from an expected healthy state, whereas NCHS defined illness as a condition limiting normal activity; consequently, the Health Watch was a more sensitive measure of illness but not as specific as the HIS.

Table 7. Illness Rates[a] by Data-Collection Period

Beginning date of 2-week data-collection period, 1977	All illnesses[b]	Respiratory	Gastrointestinal	Eye/ear	Skin	Other acute infections	Exacerbation of chronic condition	New chronic condition
April 3	11.42	5.85	2.64	0.59	0.88	0.59	0.88	[c]
April 17	11.58	6.90	1.55	1.04	0.86	0.35	0.86	[c]
May 1	10.93	7.26	1.49	1.29	0.20	0.10	0.60	[c]
May 15	10.28	6.19	2.00	1.33	0.29	0.10	0.19	0.19
May 29	8.50	4.79	1.36	0.78	0.59	0.39	0.39	0.20
June 12	8.52	5.48	1.93	0.51	0.20	0.10	0.30	[c]
June 26	4.74	2.64	1.05	0.53	0.21	0.11	0.11	0.11
July 10	8.30	3.94	2.02	1.06	0.32	0.32	0.43	0.21
July 24	10.37	6.11	1.97	1.64	0.33	0.11	0.22	[c]
August 7	10.40	6.86	1.18	0.64	0.75	0.21	0.54	0.21
August 21	9.98	6.47	1.70	0.96	0.21	0.11	0.42	0.11
September 4	10.83	7.19	2.19	0.42	0.63	[c]	0.31	0.10
September 18	12.04	8.66	1.48	0.85	0.53	0.11	0.42	[c]
October 2	15.28	11.46	1.80	0.75	0.64	[c]	0.32	0.32
October 16	10.91	7.09	2.73	0.11	0.44	[c]	0.44	0.11
October 30	8.96	6.37	1.73	0.22	0.43	[c]	0.22	[c]
November 13	13.14	9.72	2.24	0.32	0.32	0.11	0.43	[c]
Total	10.28	6.66	1.80	0.77	0.43	0.14	0.39	0.10

[a] Illnesses/1,000 person-days = $\dfrac{\text{no. of illnesses reported}}{\text{no. of person-days present}} \times 1{,}000$

[b] See Table 6 for number of illnesses

[c] No cases reported

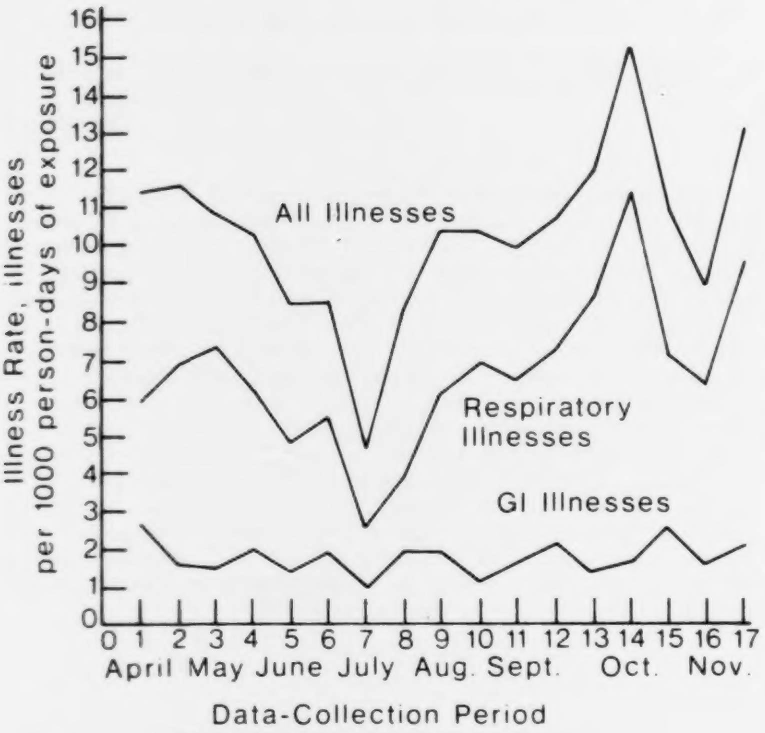


Figure 3. Seasonality of Illness Rates

Respiratory illness rates were lower in the spring and summer than in the fall, reaching peak incidence in early October (Figure 3). This relatively high occurrence appeared shortly after the beginning of school, coinciding with the increased exposure of children within the confinement of school rooms. The overall pattern of incidence of respiratory illnesses was in consonance with current knowledge of seasonality of respiratory illness. Seasonal variation was not observed for gastrointestinal illnesses, eye/ear illnesses, skin disease, other acute problems, exacerbation of chronic conditions, or new chronic conditions. Although seasonal variations for these illnesses was not expected, the rates for these illnesses were low (only gastrointestinal illness rates consistently exceeded one/1,000 person-days) and temporal variations would have been an unlikely observation.

Illness rates were examined with respect to five demographic variables (age, sex, race, family size, and length of residence in the study area) in order to determine which of these characteristics might be associated with risk of illness.

Considering age, rates of all reported illnesses (Table 8) were highest in children under 14 years old, and the rate tended to decrease as age

Table 8. Illness Rates[a] By Age[b]

Type of illness	Age groups (years) 0-2	3-5	6-13	14-18	19-59	>59	Total (all ages)
Acute							
Respiratory	13.99[c]	16.09	10.63	7.63	6.02	4.61	6.66
Gastrointestinal	3.50	3.97	2.38	2.50	1.71	1.10	1.80
Eye/ear	2.33	0.88	0.89	0.66	0.59	1.13	0.77
Skin	[d]	0.44	0.59	0.46	0.36	0.55	0.43
Other acute infections	[d]	0.22	0.15	0.13	0.10	0.23	0.14
Chronic							
Exacerbation of chronic condition	[d]	[d]	[d]	[d]	0.24	1.13	0.39
New chronic condition	[d]	0.22	[d]	0.13	0.07	0.17	0.10
Total (all illnesses)	19.83	21.82[e]	14.65	11.50	9.09	8.91	10.27
No. of people in age category	9	23	76	86	473	202	869

[a] Illness/1,000 person-days = $\frac{\text{no. of illnesses reported}}{\text{no. of person-days present}} \times 1{,}000$

[b] Age at beginning of Health Watch

[c] See Table 6 for number of illnesses

[d] No cases reported in this category

[e] Significantly different ($p < 0.01$) from total illness rates for age groups 14-18, 19-59, and > 59 years

increased. The total illness rate for 3- to 5-year-old children was significantly different (one-way analysis of variance, $p < 0.01$, in conjunction with Duncan multiple range test) from the total illness rate for the 14-to 18-, 19- to 59-, and over 59-year-old groups. About two-thirds (68.0%) of all illnesses in all age groups were of respiratory nature. Gastrointestinal conditions were more common in the age groups 0 through 18 years than in older age groups. The other illness types were less age-related and relatively infrequent in occurrence.

Regarding the sex variable as seen in Table 9, the incidence rate of all illnesses reported for females (11.8/1,000 person-days) was significantly

Table 9. Illness Rates[a] By Sex

Type of illness	Sex Male	Female	Total (both sexes)
Acute			
Respiratory	5.67[b]	7.55	6.66
Gastrointestinal	1.48	2.09	1.80
Eye/ear	0.56	0.95	0.77
Skin	0.41	0.45	0.43
Other acute infections	0.04	0.23	0.14
Chronic			
Exacerbation of chronic condition	0.36	0.41	0.39
New chronic condition	0.08	0.11	0.10
Total (all illnesses)	8.61	11.80[c]	10.28
No. of people in sex category	411	458	869

[a] Illness/1,000 person-days = $\frac{\text{no. of illnesses reported}}{\text{no. of person-days present}} \times 1{,}000$

[b] See Table 6 for number of illnesses

[c] Significantly ($p < 0.01$) greater than total illness rate for males

greater (t-test, $p < 0.01$) than that reported for males (8.6/1,000 person-days). A similar sex differential in illness was also observed by NCHS. It has also been reported that females seek more health care, excluding visits pertaining to childbearing, than males.

Illness rates by race were not examined since 92.7% of the families in the study were white. Comparisons of illness rates according to ethnicity were not undertaken.

It has been generally found that the incidence of infectious diseases is proportional to family size. There was no apparent difference in illness rates in families ranging in size from one through nine members (Table 10) in this study. These illness rates, however, included numerous non-infectious, acute conditions as well as chronic conditions, which may mask the effect of family size on communicable illnesses.

It was also hypothesized that persons living in the study area for a short time might experience more illness because they are being exposed for the first time to sewage aerosols in the environment, whereas persons who have been exposed for longer periods of time were infected and are subsequently immune to these environmental agents. Not all reported illnesses are infectious in nature, and, as will be shown later, only about one of six reported illnesses in children can be associated with an infectious agent. Although no association between length of residence and illness rate is readily apparent (Table 11), the inverse relationship of illness rate and length of residence may be real. Future studies should document this relationship, with laboratory data to confirm the incidence of infectious disease.

Table 10. Illness Rates[a] By Family Size

	Family size (no. of members in household)									Total (all family sizes)
Type of illness	1	2	3	4	5	6	7	8	9	
Acute										
Respiratory	6.04[b]	6.49	4.98	7.72	7.72	5.54	6.85	4.94	10.28	6.66
Gastrointestinal	1.46	1.46	1.59	2.84	1.09	1.51	0.36	0.62	0.94	1.80
Eye/ear	1.04	0.93	0.94	0.65	0.52	0.76	[c]	0.31	1.87	0.77
Skin	[c]	0.58	0.29	0.60	0.16	0.42	[c]	0.62	[c]	0.43
Other acute infections	0.42	0.17	0.11	0.16	0.10	[c]	[c]	0.31	[c]	0.14
Chronic										
Exacerbation of chronic condition	2.92	0.82	0.14	0.22	[c]	0.08	[c]	[c]	[c]	0.39
New chronic condition	[c]	0.17	[c]	0.13	0.10	0.08	[c]	[c]	[c]	0.10
Total (all illnesses)	11.87	10.61	8.04	12.33	9.60	8.39	7.21	6.80	13.08	10.28
No. of families in size category	28	107	56	62	21	10	3	2	1	290

[a] $\text{Illness/1,000 person-days} = \dfrac{\text{no. of illnesses reported}}{\text{no. of person-days present}} \times 1{,}000$

[b] See Table 6 for number of illnesses

[c] No cases reported in this category

Table 11. Illness Rates[a] By Length of Residence

Type of illness[b]	Length of residence (years)							
	<1	1-5	6-10	11-20	21-30	31-40	>40	Total
Acute								
Respiratory	7.77	8.11	6.57	5.40	6.91	4.47	4.98	6.65
Gastrointestinal	1.80	2.61	1.14	1.80	1.56	[c]	1.66	1.80
Eye/ear	0.57	1.07	0.57	0.54	1.16	[c]	[c]	0.77
Skin	1.04	0.70	0.18	0.48	[c]	[c]	3.32	0.43
Other acute infections	[c]	0.09	0.07	0.16	0.25	0.56	[c]	0.14
Chronic								
Exacerbation of chronic condition	0.10	0.64	0.04	0.30	0.69	0.56	[c]	0.39
New chronic condition	[c]	0.09	0.14	0.10	0.11	[c]	[c]	0.10
Total (all illnesses)	11.27	13.30	8.72	8.79	10.68	5.59	9.97	10.27
No. of persons in residence category	56	206	159	289	145	11	2	868[d]

[a] Illnesses/1,000 person-days = $\frac{\text{no. of illnesses reported}}{\text{no. of person-days present}} \times 1{,}000$

[b] See Table 6 for number of illnesses

[c] No cases reported in this category

[d] Length of residence unknown for one person

Microbiological Analyses of Specimens Collected. Eighty Health Watch participants provided stool specimens representing 44.0% of the expected number of providers. They submitted 541 stool specimens (17.7% of the total number of stool specimens expected), indicating that not even the 80 participants provided all the specimens expected. Laboratory testing for bacteria included a search for any unusual isolates. The tissue culture systems used in the laboratory for virus isolation were most sensitive for recovering adeno-, myxo- and enteroviruses.

As shown in Table 12, two *Salmonella* spp. were recovered from the 80 persons tested for 8 months. One isolate was from a 5-year-old girl; the other was from an adult female. Neither had reported clinical illness. This was equivalent to an incidence rate of 3.75 cases/100 person-years, which, compared to 12 cases/100,000 person-years reported in the United States by the Center for Disease Control, was more than expected. The rate of permanent, asymptomatic carriers of *Salmonella* in the United States is believed to be 0.2 to 5.0/100 of the normal population. Whether these two cases were carriers or not was not established.

Viruses isolated from the 541 stool specimens were members of three enterovirus groups. No adenoviruses or other cytopathic agents were recovered that could have been detected in the cell culture systems used (Table 12). Seven polioviruses were recovered, and all of these were from young children with a recent history of poliovirus immunization. One Coxsackievirus B3 was isolated from a child. The remaining 13 virus isolates were echovirus types 3, 6, 12, 22, and 25. The incidence of echovirus infections was highest in the 3- through 6-year-old groups but occurred in the other age groups to 13 years old. Only one echovirus infection occurred (Echovirus 12) in an adult. These coxsachievirus and echovirus types recovered during this study group are commonly associated with respiratory-enteric illness or with diarrheal disease and often are asymptomatic infections.

Table 12. Organisms Isolated from Stool Specimens[a] by Age of Participants[b]

Isolates	0-2	3-4	5-6	7-12	13-18	19-59	Total
	Age groups (years)						
Stool specimens							
No. of people asked to give specimens	8	14	20	69	24	45	180
No. people who gave at least one	6	10	10	23	8	23	80
No. specimens obtained	43	73	72	154	46	153	541
Bacterial isolates[c]							
Salmonella	0	0	1	0	0	1	2
Viral isolates[c]							
Polio 1	3	0	0	0	0	0	3
Polio 3	3	0	0	1	0	0	4
Coxsackie B3	0	0	1	0	0	0	1
Echo 3	0	0	1	3	0	0	4
Echo 6	0	1	1	0	0	0	2
Echo 12	0	1	1	0	0	1	3
Echo 22	1	0	1	0	0	0	2
Echo 25	0	1	1	0	0	0	2
Total viral	7	3	6	4	0	1	21
Total stool[c] isolates	7	3	7	4	0	2	23

[a] Specimens requested on a biweekly basis of childen 12 years of age and under and of one adult in each family thereof; specimens obtained from May, 1977 through November, 1977

[b] Age at beginning of Health Watch

[c] For cases of multiple consecutive isolations of a single type of organisms for one person, only the first isolation was tabulated

An interpretation of the incidence of these laboratory-confirmed infections based on examination of stool specimens is, at best, crude. The incidence of *Salmonella* spp. in stool specimens has been considered above, and the poliovirus isolates were vaccine-related. The recovery of 14 coxsackievirus and echoviruses from 80 persons submitting 541 specimens over an 8-month period yielded a crude rate of 17.5 enterovirus isolations/100 persons/8-months.

Studies have been conducted showing that the percentage of healthy children shedding enteroviruses ranged from 4.6 to 14.9%. The Health Watch study period covered those seasons of the year in which enterovirus infection rates were expected to be highest, accounting for the fact that the rate found here was in the upper limits of the expected rate.

Of the 111 children 12 years old and under in families recruited into the Health Watch, 81 submitted 757 throat specimens for an average of 9.3 specimens/child during the study (Table 13). Theoretically, 17 specimens could have been collected from each participating child; actually, nearly 55% of the expected number of throat specimens were collected. Compared with the 17.7% of expected stool specimens collected, it is apparent that providing throat swabs was more acceptable than submitting fecal samples. It was also noted that the age distribution of the 81 children providing throat specimens was similar to that of the original 111 children in the recruited families.

A total of 177 bacterial and viral isolates was made from the 757 throat specimens received. On the average, 4.5 bacterial isolates were recovered from each child in the 0-to 2-year age group, 2.7/child in the 3- to 4-year age group, and 1.8 in the 5- to 12-year age group. A similar decrease in isolation with increasing age was also possible for viral infections, but the numbers were too small to be significant.

Of the 20 different bacterial types isolated, *Klebsiella pneumoniae*, *Staphylococcus aureus*, and *Enterobacter* spp. were the most frequently recovered in the 0- to 2- and 3- to 4-year age groups. *S. aureus* was the

Table 13. Organisms Isolated from Throat Specimens[a] by Age of Participants[b]

Isolates	Age groups (years)							
	0-2		3-4		5-12		Total	
	No.	Rate[c]	No.	Rate	No.	Rate	No.	Rate
Throat specimens								
No. people asked to give specimens	8		14		89		111	
No. people who gave at least one	6		11		64		81	
No. specimens received	48		108		601		757	
Bacterial isolates[d]								
Staphylococcus aureus	6	100.0	8	72.7	56	87.4	70	86.4
Beta-streptococcus, Group A	0	0.0	1	9.1	14	22.4	15	18.5
Beta-Streptococcus, not A or D	0	0.0	2	18.2	17	26.5	19	23.5
Salmonella enteritidis (Newport)	0	0.0	1	9.1	0	0.0	1	1.2
Klebsiella ozaenae	2	33.3	0	0.0	0	0.0	2	2.5
Klebsiella pneumoniae	9	150.0	2	18.2	4	6.2	15	18.5
Escherichia coli	2	33.3	1	9.1	5	7.8	8	9.9
Enterobacter aerogenes	0	0.0	1	9.1	0	0.0	1	1.2
Enterobacter agglomerans	1	16.7	2	18.2	6	9.4	9	11.1
Enterobacter cloacae	4	66.7	6	54.5	5	7.8	15	18.5
Enterobacter hafniae	0	0.0	0	0.0	1	1.6	1	1.2
Serratia liquefaciens	0	0.0	1	9.1	3	4.7	4	4.9
Serratia marcescens	0	0.0	0	0.0	1	1.16	1	1.12
Serratia rubidaea	0	0.0	0	0.0	1	1.6	1	1.2
Aeromonas hydrophilia	0	0.0	2	18.2	1	1.6	3	3.7
Citrobacter diversus	0	0.0	1	9.1	0	0.0	1	1.2
Citrobacter freundii	2	33.3	0	0.0	0	0.0	2	2.5
Pseudomonas spp.	0	0.0	1	9.1	2	3.1	3	3.7
CDC, Group IV C-2	0	0.0	0	0.0	1	1.6	1	1.2
CDC, Group V, E-1	1	16.7	0	0.0	0	0.0	1	1.2
Total bacterial	27		29		117		173	
Viral isolates[d]								
Adenovirus 2	0		0		1		1	
Echovirus 6	0		2		1		3	
Total viral	0		2		2		4	
Total throat isolates	27		31		119		177	

[a] Specimens requested on a biweekly basis from children 12 years of age and under; specimens obtained from May, 1977 through December, 1977

[b] Age at beginning of Health Watch

[c] Number of isolated/100 persons

[d] For cases of multiple consecutive isolations of a single type of organism for one person, only the first isolation was tabulated

most frequent isolate in the 5- to 12-year-old group, followed by beta-hemolytic streptococci. The number of different bacterial genera isolated was the smallest in the youngest age group and more different genera were recovered with increasing age.

Only four virus isolates were recovered: three Echovirus 6 were isolated in the 3-to 12-year-olds, and one Adenovirus 2 in the 5-to 12-year-old group. No viral isolates were made in children 2 years old or younger. Hemadsorption tests were done on all cell cultures inoculated with these specimens and none were positive, suggesting that influenza, parainfluenza, measles, or mumps virus infections had not occurred in this population.

In summary, 173 separate, nonnormal flora, bacterial isolates were recovered from routine throat swab specimens of 81 children 1 through 12 years of age. In contrast, only two unusual bacteria isolates were identified in stool specimens from persons 0 through 59 years of age. Virus isolates were about three times more frequent from stools (excluding the polioviruses associated with immunization) than from throat specimens. The recovery of more enterovirus from stool than from throat specimens was expected because infections of the oropharynx persist for only a few days whereas these infections continue in the intestinal tract for a month or more (whether or not there is associated clinical illness) increasing the chance of recovery from stool specimens when biweekly specimens are obtained. The information derived from this microbiological survey of throat and stool specimens did not allow a statement of the significance of the findings because of the small number of participants involved and of the small number of bacteria and viruses recovered. The findings were of value for descriptive purposes for consideration later when the air quality data were analyzed.

Serological Analyses. A total of 318 persons 6 years of age and older gave paired blood samples of 837 persons requested to give two blood samples, pre- and post-study. The sera of each paired blood sample were tested for antibodies to 12 viral agents. These included Polioviruses 1 through 3; Coxsackieviruses B1 through B5, and Echoviruses 3, 6, 9 and 12 which: 1) are known to commonly populate sewage; 2) are stable and could be emitted into sewage aerosols; and 3) are known to be common pathogens for man which may cause either clinical or subclinical illness. Enteric viruses have been associated with gastrointestinal, respiratory, cutaneous and/or combined illness.

For the analysis of the serological data, it was necessary to calculate the number of susceptibles for each virus under consideration, since any one person could be immune to one virus and susceptible to another virus. The following equations were used for Table 14:

$$\text{no. susceptible} + \text{no. immune} = \text{total paired blood donors} \qquad \text{(Equation 2)}$$

$$\text{no. susceptible} = \begin{array}{c}(\text{no. of persons with initial titer} < 10)\\ \text{plus}\\ (\text{all other persons with fourfold rise})\end{array} \qquad \text{(Equation 3)}$$

The incidence (Table 14) of Coxsackievirus B4 infections was the highest observed, 17.97/100 persons, whereas the B1 rate was the lowest,

Table 14. Incidence of Viral Infections Among Susceptible Blood Donors

Virus antigen	No. of persons immune[a]	No. of persons susceptible[b]	No. of persons seroconverting[c]	Incidence[d] of viral infections
Coxsackie B1	48	270	4	1.48
Coxsackie B2	137	181	12	6.63
Coxsackie B3	140	178	15	8.43
Coxsackie B4	190	128	23	17.97
Coxsackie B5	98	220	9	4.09
Echo 3	119	199	7	3.52
Echo 6	140	178	8	4.49
Echo 9	94	224	3	1.34
Echo 12	94	224	10	4.46

[a] No. of persons with initial antibody titer ≥ 10 minus no. of persons with fourfold rise whose initial titer was > 10

[b] No. of persons with initial antibody titer < 10 plus all other persons with fourfold rise

[c] All persons with fourfold rise in antibody titer

[d] $$\text{Incidence of viral infections} = \frac{\text{no. of persons seroconverting}}{\text{no. of persons susceptible}} \times 100$$

1.48/100 persons. The listing of the number of persons immune and susceptible to the coxsackieviruses emphasises that the majority of persons were susceptible to these agents, except for Coxsackievirus B4. The infection rates for Echoviruses 3, 6, 9, and 12 were similar to each other and were generally lower than those observed for the coxsackieviruses. The number of susceptibles was similar to the number susceptible to the coxsackieviruses.

The incidence of these viral infections was then examined by age groups (Table 15). Infections by Coxsackievirus B1 and B2 were not observed in the 6-through 18-year-old groups, but occurred in all other age categories. The incidence of B3 infections was similar in all age groups, whereas B4 infection rates increased remarkably with increasing age to the maximum of over 30/100 persons over 59 years old. Coxsackievirus B5 infections were relatively more frequent in children and adults than in the over 59-year-old group.

Echovirus 3, 6, and 9 infection rates were similar in all age groups; Echovirus 12 infections were not observed in the 6-through 18-year-old group and the rate increased from about 4/100 in the 19-through 59-year-old group to 10/100 in the over 59-year-old group. With only a few exceptions, the number of susceptible persons in each age group exceeded the number immune. The incidence data presented here for these few infectious diseases are of important descriptive nature, and they are not intended for statistical interpretation since a hypothesis for these data alone was not the purpose of this portion of the study. Biometric analyses of these data will be applied when they are considered with the environmental air quality data.

Table 15. Incidence of Viral Infections Among Susceptible Blood Donors by Age

	Age groups (years)											
	6-18				19-59				>59			
Virus antigen	No. of immune persons[a]	No. of susceptible persons[b]	No. of persons serocon-verting[c]	Incidence of viral infection[d]	No. of immune persons	No. of susceptible persons	No. of persons serocon-verting	Incidence of viral infection	No. of immune persons	No. of susceptible persons	No. of persons serocon-verting	Incidence of viral infection
Coxsackie B1	5	35	0	0.00	32	160	3	1.87	11	75	1	1.33
Coxsackie B2	10	30	0	0.00	82	110	9	8.18	45	41	3	7.32
Coxsackie B3	12	28	2	7.14	89	103	9	8.74	39	47	4	8.51
Coxsackie B4	15	25	1	4.00	114	78	14	17.95	60	26	8	30.77
Coxsackie B5	16	24	1	4.17	65	127	7	5.51	17	69	1	1.45
Echo 3	15	25	2	8.00	55	137	4	2.92	49	37	1	2.70
Echo 6	14	25	1	4.00	77	115	5	4.35	48	38	2	5.26
Echo 9	7	23	1	3.03	59	133	1	0.75	28	58	1	1.72
Echo 12	1	39	0	0.00	58	134	5	3.73	35	51	5	9.80

[a] No. of persons with initial antibody titer ≥ 10 minus no. of persons with fourfold rise whose initial titer was > 10

[b] No. of persons with initial antibody titer < 10 plus all other persons with fourfold rise

[c] All persons with fourfold rise in antibody titer

[d] Incidence of viral infections = $\frac{\text{no. of persons seroconverting}}{\text{no. of persons susceptible}} \times 100$

ENVIRONMENTAL MONITORING PROGRAM

Methods

Measurements of air pollutants were taken on a regular basis at the plant and in the surrounding area out to 1.6 km. The air pollutants included total aerobic bacteria-containing particles, hereafter referred to as total viable particles (TVP), total suspended particulate matter (TSP), NO_2, SO_2, Cl_2, NH_3 and H_2S. TSP filters were also analyzed for nitrates (NO_3^-) and sulfates ($SO_4^=$), As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Sb, Se, Sn and V. Total coliform (TCP) were collected and analyzed over the final 2½ months of the project. Grab samples of sewage entering the aeration tanks, taken concurrently with the air samples, were analyzed for the same pollutants. Sampling methods and a description of the sampling periods for viable and nonviable pollutants are given in Tables 16 and 17.

A meteorological station was installed on the plant site for continuous monitoring of wind speed and direction, temperature, relative humidity, ultraviolet and total radiation, and rainfall. This equipment provided integrated wind direction data for use in the selection of the monitoring sites.

The environmental monitoring data were used to develop a personal exposure index for the residents of the study area. This was accomplished by using maps of concentration isopleths generated from the air pollution data. The personal exposure index takes into account meteorological factors as well as the actual measured pollution levels.

Selection of Monitoring Sites

The sites for viable particle sampling were selected to maximize the probability of collecting organisms of plant origin. Three sites in a line at various distances downwind from the aeration tanks and one upwind were chosen for this purpose. Based on dispersion distances observed in previous studies of airborne organism distributions and the geographic distribution of residences in the study area, 16 community sampling sites were selected in two concentric circles of 0.8 km and 1.6 km radius from the plant, and four on-plant sites were chosen along the north, east, south, and west edges of the aeration tank batteries. The 16 community viable sampling sites were chosen to closely follow the eight major wind direction patterns (N↔S, E↔W, NW↔SE, and SW↔NE). At each sampling site, a location for the mobile monitoring unit was chosen away from all tall buildings or other obstructions. For on-plant site selection, wind direction was categorized into one of four 90° sectors: NE to SE, SE to SW, SW to NW, and NW to NE.

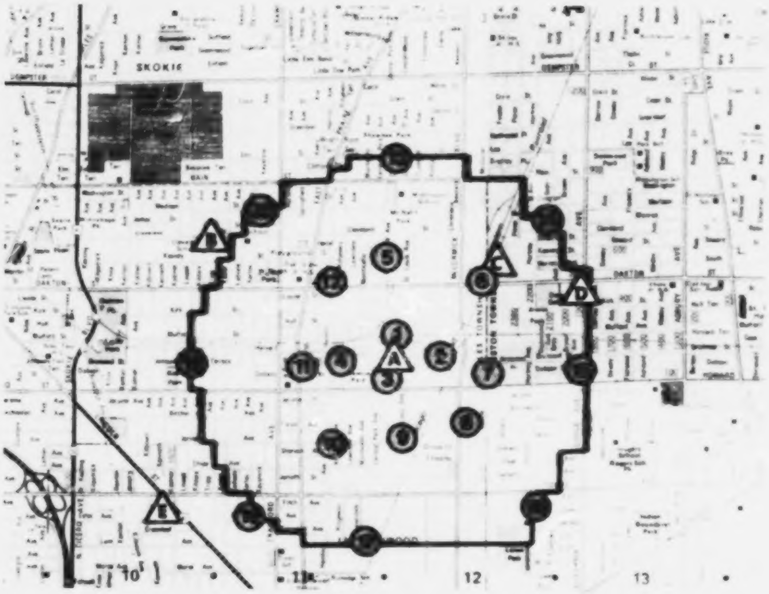
The monitoring sites selected for the nonviable air measurements were based on different criteria than for the viable protocol. Each site was a permanent facility. The site at the plant was located near the aeration tanks. Two community sites were selected in high-density residential areas 1.6 km from the aeration tanks. Two other sites were located northeast of the plant approximately 0.8 and 1.6 km from the tanks. These selections were based on 1975 prevailing wind data for the north suburban area. The nonviable monitoring sites required access to a 110-volt electrical supply. It was also necessary to locate the equip-

Table 16. Sampling Methods: Viable Constituents

Constituent	Sampler	Air flow rate	Collection time	Media	Incubation	Sampling period
Total aerobic bacteria containing particles (TVP)	Andersen - 2000 Cascade Impactor	0.028 m³/min. (1 fm)	15 min	Trypticase soy-agar (BBL) with actidione	35°C 48 ± 5 hours	5 intervals in each 2-week period, April 18 - Nov. 30, 1977.
Total coliform-containing particles (TCP)	Andersen - 2000 Casade Impactor	0.028 m³/min	30 min	M-endo broth with 1.5% Bacto-agar (Difco)	35°C 24 ± 2 hours	Same as aerobic bacteria, except started Sept. 13 - Nov. 30, 1977.
	Litton large volume air sampler (LVAS)	1.0 m³/min fluid flow rate -6 to 10 ml/min Voltage - 10-15 kilovolts	15 min	Phosphate buffered water, 0.01% phenol red and 25% trypticase soy broth (BBL)-collection. M-endo-broth - assay	35°C 24 ± 2 hours	Approximately every 2 weeks, Aug. 24 to Nov. 30.
Fecal coliform-containing particles	Litton large volume air sampler (LVAS)	Same as above	Same as above	Same as above except M-FC broth used for assay.	44 ± 0.5°C (water bath) 24 ± 2hours	Same as above

Table 17. Sampling Methods: Non-Viable Constituents

Constituent	Sampler	Air flow rate	Collection time	Media	Analysis method	Sampling period
Total suspended particulates	RAC hi-volume air sampler	45 - 60 cfm	24 hours	Glass fiber filters	Pre and post weight	Every fifth day, May 19 - Nov. 30, 1977.
Trace metals (V, Cr, Mn, Ni, Cu, As, Se, Cd, Sn, Sb, Hg, Pb)	RAC hi-volume air sampler	40 - 50 cfm	24 hours	Whatman 541 filters	X-ray fluorescence spectrometry	Every fifth day, June 28 - Nov. 30.
Gases (NO_2, SO_2, Cl_2, NH_3, H_2S)	RAC five - gas bubbler trains	200 ml/min-SO_2, NO_2, Cl_2, H_2S, 5 l/min-NH_3	24 hours	Specific collection Fluid for each gas	Spectrophotometric methods, specific for each gas.	Every fifth day, May 19 - Nov. 30



SAMPLE LOCATIONS: ○ VIABLE, △ NON-VIABLE

Figure 4. Map of Sampling Sites

ment on a relatively flat roof not easily accessible to vandals and far from building exhaust systems.

The on-plant sites (1–4), community sites (5–10), and non-viable sites (A–E) are depicted in Figure 4.

One-liter grab samples were collected at the inlet manifold of one of the aeration tank batteries in order to determine the concentrations of the pollutants which might be aerosolized.

RESULTS

The environmental monitoring program was designed to answer two questions: 1) What are the exposures of people living in the study area to air pollutants, and 2) Is the Metropolitan Sanitary District's North Side Sewage Treatment Plant a source of air pollution for the surrounding community?

Summary of Environmental Data

A detailed record of the meteorological conditions during the study period was an important component of both the environmental sampling and data analysis efforts.

The wind rose diagram for the study period is based on on-plant measurements and is shown in Figure 5. It shows no strong predominant wind pattern. The most frequent wind direction was southwest for only

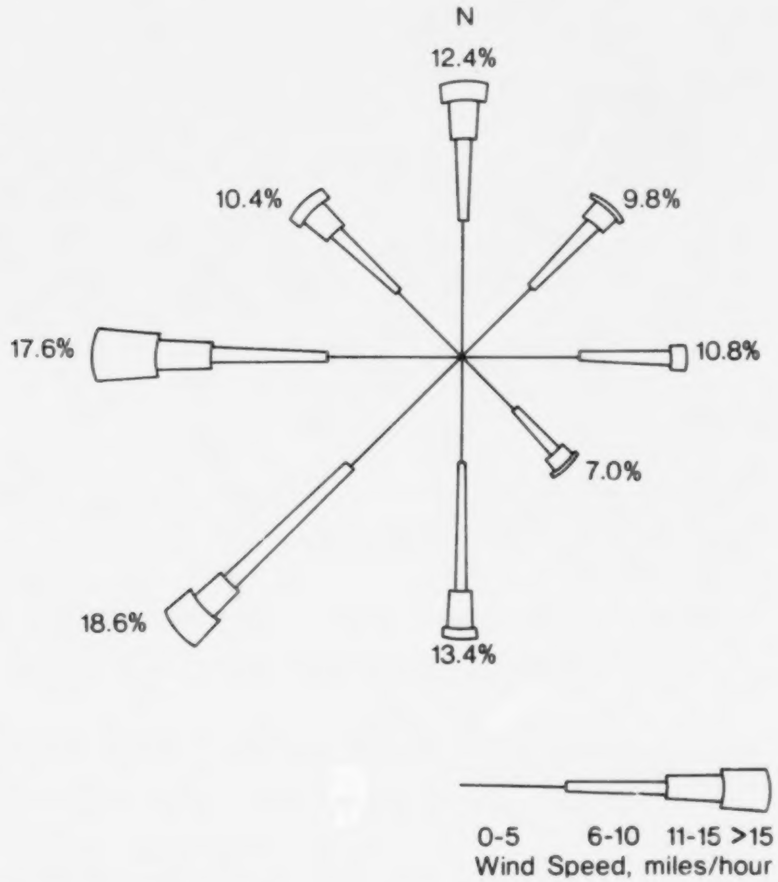


Figure 5. Wind Rose Diagram Based on On-Plant Measurements During Study Period

18.6% of the study-period hours. The most frequent wind direction measured at Midway was south for 24.6% of the study-period hours.

Sampling runs consisted of air sampling at four sites and the collection of an on-plant sewage sample. These sites, which were selected based on the previous hour's vector-averaged wind direction, were 0.8 km upwind from the plant, on the plant grounds downwind of the aeration tanks, 0.8 km downwind of the plant, and 1.6 km downwind of the plant. Sampling sites 1 through 4 (Figure 4) represent position "on-plant downwind." Sites 13 through 20 were always position "1.6 km downwind." Sites 5 through 12 were positions 0.8 km upwind or 0.8 km downwind depending on the wind direction.

A total of 72 Andersen runs for total viable particles and 26 Andersen runs for total coliform and 83 sewage samples for total aerobic, coliform, and fecal coliform bacteria were collected. Forty-eight of the viable runs were in the summer and 24 in the fall. Twenty-two of the 26 total coliform runs were in the fall. Table 18 shows the average total viable particle and average total coliform particle concentrations for the four positions. Table 19 shows seasonal differences for total viable particles by position. Table 20 shows average total viable particle and coliform concentrations by sampling location and wind direction. Table 21 gives average concentrations for total viable and total coliform particles summarized by median size distribution. About 70% appeared to be greater than 4.7μm in diameter. On the average, 95% of the total viable particles discharged from the plant were greater than 2.1μm, while 99% of the total coliform particles were greater than 1.1 μm. Airborne measurements of total and fecal coliform taken with the LVAS are shown in Table 22. Average sewage concentrations by month and for the 8-month study period are shown in Table 23.

Sampling for nonviable pollutants was carried out every 5 days from April 4 to Novemer 30. Air samples for all 20 parameters were collected at the plant for every collection period. Of the remaining four sites, two were used to collect TSP, $SO_4^=$, and NO_3^- while two were used to collect samples of the five gases and 12 metals.

Table 18. Average TVP and TCP Concentrations by Sampling Site Position

Sampling site position[a]	Total viable particles Mean concentration (particles/m³)	Standard deviation (particles/m³)	Total coliform Mean concentration (particles/m³)	Standard deviation (particles/m³)
0.8 km upwind	143 (62)[b]	123	1.15 (26)[b]	1.8
On-plant downwind	376[c] (68)	339	6.87[c] (26)	8.9
0.8 km downwind	198[c] (68)	155	1.15 (25)	2.0
1.6 km downwind	218[c] (60)	262	1.01 (24)	2.2

[a] Position relative to plant

[b] Number of samples in parentheses

[c] Significantly greater than the upwind value ($p < 0.05$)

Table 19. TVP Concentrations by Season and Sampling Site Position

Sampling site position[a]	Total viable particle concentrations (particles/m³) Summer Mean concentration	 Summer Standard deviation	 Fall Mean concentration	 Fall Standard deviation
0.8 km upwind	143 (38)[b]	125	144 (24)[b]	123
On-plant downwind	379 (43)	385	372 (25)	245
0.8 km downwind	186 (< 4)	152	221 (24)	161
1.6 km downwind	230 (37)	281	199 (23)	232

[a] Position relative to plant

[b] Number of samples in parentheses

Table 20. Average TVP and TCP Concentrations by Sampling Site and Wind Direction

Sampling site	Distance from plant (km)	Downwind concentrations (particles/m³): Total viable particles	Downwind concentrations (particles/m³): Coliform	Upwind concentrations (particles/m³): Total viable particles	Upwind concentrations (particles/m³): Coliform
1	—	447 (12)[a]	3.96 (7)[a]		
2	—	381 (21)	3.42 (12)		
3	—	347 (21)	17.08 (5)		
4	—	354 (13)	12.20 (2)		
5	0.8	268 (6)	1.10 (6)	59 (7)[a]	0.37 (3)[a]
6	0.8	191 (8)	2.60 (3)	157 (10)	
7	0.8	155 (14)	1.20 (9)	135 (12)	0.00 (2)
8	0.8	199 (7)	1.10 (2)	378 (3)	
9	0.8	294 (7)	0.37 (3)	227 (5)	0.94 (7)
10	0.8	93 (9)		161 (6)	0.37 (3)
11	0.8	228 (13)	0.00 (12)	118 (16)	1.97 (9)
12	0.8	232 (4)		54 (3)	1.65 (2)
13	1.6	169 (6)	2.03 (6)		
14	1.6	580 (9)	0.73 (3)		
15	1.6	200 (10)	1.10 (8)		
16	1.6	60 (6)	0.00 (2)		
17	1.6	174 (6)	0.00 (3)		
18	1.6	248 (8)			
19	1.6	171 (12)	0.55 (2)		
20	1.6	144 (3)			

[a] Number of samples in parentheses

Table 21. Median Size Distributions for TVP and TCP Based on All Samples

Stage	Diameter (μm)	Total viable particles: TVP/m³	Total viable particles: %	Total coliform: Coliform/m³	Total coliform: %
1	> 7	103	43	1.28	50
2	4.7 – 7	54	23	0.65	25
3	3.3 – 4.7	43	18	0.40	16
4	2.1 – 3.3	18	8	0.13	5
5	1.1 – 2.1	13	6	0.08	3
6	0.65 – 1.1	5	2	0.02	1
Total		236	100	2.56	100

Table 22. Average Concentrations of Total Coliform and Fecal Coliform Collected with an LVAS by Distance from Plant

Location	Total Coliform/m³[a]: Mean concentration	Total Coliform/m³[a]: Standard deviation	Fecal Coliform/m³: Mean concentration	Fecal Coliform/m³: Standard deviation
on-plant upwind	0.56 (8)[b]	0.47	0.11 (7)[b]	0.27
on-plant downwind	9.87 (7)	6.82	1.91 (8)	2.71
0.8 km downwind	0.37 (6)	0.46	0.04 (7)	0.08
1.6 km downwind	2.72 (4)[c]	2.35	0.29 (3)[c]	0.50

[a] Significantly different at the 0.01 level by analysis of variance

[b] Number of samples in parentheses

[c] One sample was collected at site 14

Table 23. Summary of Sewage Microbiology

Averaging period 1977	Total aerobic bacteria (10^7/100 ml)			Total coliform (10^6/100 ml)			Fecal coliform (10^4/100 ml)		
	No. of samples	Mean	Standard deviation	No. of samples	Mean	Standard deviation	No. of samples	Mean	Standard deviation
April	6	155	96	6	37	16	6	35	32
May	10	525	1,323	10	65	109	10	67	67
June	11	20	19	11	19	12	11	40	29
July	11	59	54	11	26	24	11	58	34
August	5[a]	889	1,789	11	104	85	11	128	59
September	10[b]	30	40	11	70	44	11	120	52
October	10	40	21	10	64	30	10	73	36
November	13	39	24	13	42	25	13	79	59
April-November	78	165	659	83	54	59	83	78	56

[a] Plus one sample of $> 10^7$/100 ml; five samples were $> 10^9$/100 ml

[b] Plus one sample of $< 10^4$/100 ml

Tables 24 through 26 show the particulate matter and gas data averaged by location for the study period. The maximum average assumes all concentrations below the detection limit are equal to the detection limit. The minimum average assumes that all concentrations below the detection limit are equal to zero. The actual concentration falls between these averages. All concentrations are in μg/m3. A summary of TSP particle size distribution (based on plant site measurements) is given in Table 27. About 50% (by weight) were greater than 3.3μm. A summary of nonviable sewage data is shown in Table 28. Number of samples, detection limits, study period average concentrations, and standard deviations of all 12 pollutants measured are included.

Development of Personal Exposure Indices

Two viable and nine nonviable pollutants were selected for the model to predict personal exposure indices for use in the health analysis. The main criterion used in selecting these indices was the ability to reliably measure the pollutant. In the case of fecal coliforms and many of the metals, the study area concentrations were close to, or below, detection limits.

The upwind and downwind average concentrations of total viable particles and total coliform particles by sampling sites were summarized in Table 20. Figures 6 and 7 show the data, separated by each sampling sites' wind relation to the plant (up or downwind), projected over the entire study area. These maps were generated using the SYMAP program. This program uses an inverse-square weighting scheme to interpolate concentrations at every point within the study area from the concentrations at the 20 sampling locations. It was judged to be the best model available because it integrates all meteorological and topographical conditions by using all the air pollution data to interpolate concentrations in the study area. A comparison of the downwind maps to the upwind maps identifies the plant as a source of total viable and total coliform particles within certain portions of the study area. The downwind total viable particle map also identifies a second source of total viable particles near site 14. This source does not emit coliform particles.

Table 24. Average Ambient Trace Element Concentrations by Site

	Concentration[b] (µg/m³)											
	V		Cr		Mn		Ni		Cu		As	
Sampling site[a]	Average max.[c]	Average min.[d]	Average max.	Average min.	Average max.	Average min.	Average max.	Average min.	Average max.	Average min.	Average max.	Average min.
A	0.0045	0.0021	0.0318	0.0000	0.0417	0.0292	0.0118	0.0003	0.2141	0.2141	0.0109	0.0012
B	0.0041	0.0014	0.0277	0.0000	0.0361	0.0183	0.0100	0.0000	0.3691	0.3691	0.0086	0.0000
C	0.0043	0.0019	0.0327	0.0058	0.0478	0.0380	0.0115	0.0006	0.4247	0.4247	0.0099	0.0007
D	0.0040	0.0017	0.0287	0.0000	0.0459	0.0376	0.0106	0.0006	0.3971	0.3971	0.0100	0.0019
E	0.0073	0.0047	0.0385	0.0118	0.0363	0.0262	0.0104	0.0000	0.3123	0.3123	0.0093	0.0000

	Concentration[b] (µg/m³)											
	Se		Cd		Sn		Sb		Hg		Pb	
Sampling site	Average max.	Average min.	Average max.	Average min.	Average max.	Average min.	Average max.	Average min.	Average max.	Average min.	Average max.	Average min.
A	0.0090	0.0025	0.0157	0.0042	0.0124	0.0037	0.0120	0.0018	0.0134	0.0015	0.6083	0.6083
B	0.0081	0.0029	0.0131	0.0000	0.0111	0.0021	0.0122	0.0032	0.0112	0.0021	0.7412	0.7412
C	0.0084	0.0017	0.0149	0.0018	0.0117	0.0022	0.0114	0.0000	0.0129	0.0013	0.8400	0.8400
D	0.0074	0.0021	0.0148	0.0033	0.0115	0.0022	0.0114	0.0018	0.0126	0.0026	0.6455	0.6455
E	0.0086	0.0041	0.0170	0.0069	0.0109	0.0022	0.0117	0.0024	0.0116	0.0000	0.8394	0.8394

[a] See Figure 4 for key to sampling sites

[b] Determined from Whatman 541 filters analyzed by energy dispersive X-ray fluorescence spectrometry

[c] Average maximum assumes all concentrations below the detection limit are equal to the detection limit

[d] Average minimum assumes all concentrations below the detection limit are equal to zero

Table 25. Average Gas Concentrations by Site

Sampling site[a]	Concentration ($\mu g/m^3$)									
	Cl_2		NH_3		NO_2		H_2S		SO_2	
	Average max.[b]	Average min.[c]	Average max.	Average min.	Average max.	Average min.	Average max.	Average min.	Average max.	Average min.
A	13.55	11.05	2.90	0.36	46.39	42.72	0.88	0.11	10.49	3.27
B	15.25	11.80	2.96	0.43	53.59	47.32	0.72	0.00	13.98	7.22
C	13.39	11.03	2.47	0.17	60.57	57.01	0.97	0.22	13.68	7.08
D	16.73	13.59	2.76	0.57	54.85	54.85	1.06	0.27	15.80	8.76
E	14.81	11.42	2.66	0.25	53.83	53.49	0.73	0.00	8.76	3.11

[a] See Figure 4 for key to sampling sites

[b] Average maximum assumes all concentrations below the detection limit are equal to the detection limit

[c] Average minimum assumes all concentrations below the detection limit are equal to zero

Table 26. Average Ambient TSP, Nitrate, and Sulfate Concentrations by Site

	Average ambient concentration[b] (μg/m³)		
Sampling site[a]	TSP	NO_3	SO_4
A	77.56	1.60	14.06
B	74.47	1.40	11.31
C	87.45	1.46	13.43
D	82.21	1.57	13.03
E	68.13	1.44	12.04

[a] See Figure 4 for key to sampling sites
[b] Determined from glass-fiber filters

Table 27. Mean TSP Size Distribution (Plant Site)

Stage	Diameter (μm)	Average concentration[a] (μg/m³)	Weight (%)
1	> 7.0	21.0	28.7
2	3.3-7.0	15.0	20.6
3	2.0-3.3	9.8	13.4
4	1.1-2.0	10.7	14.8
5	0.01-1.1	16.3	22.5
Total		72.8	100.0

[a] Based on 17 samples

Table 28. Summary of Nonviable Sewage Data

Constituent	No. of samples	No. of samples above detection limit	Detection limit (μg/l)	Study period ave. conc. (μg/l)	Standard deviation (μg/l)
$SO_4^{=}$	27	27	0.1	26.6[a]	17.0[a]
NO_3^{-}	27	27	0.1	7.6[a]	4.6[a]
V	19	0	12	[b]	[b]
Ni	19	19	2	215	54
Cu	19	19	2	218	251
As	19	19	60	171	69
Se	19	0	2	[b]	[b]
Cd	19	19	3	129	56
Sn	19	19	1	60	15
Sb	19	10	1	1.4[c]	1.9[c]
Hg	19	0	4	[b]	[b]
Pb	19	19	5	280	141

[a] Concentrations in mg/l
[b] All samples below detection limit
[c] Samples below detection limit averaged as 0 μg/l

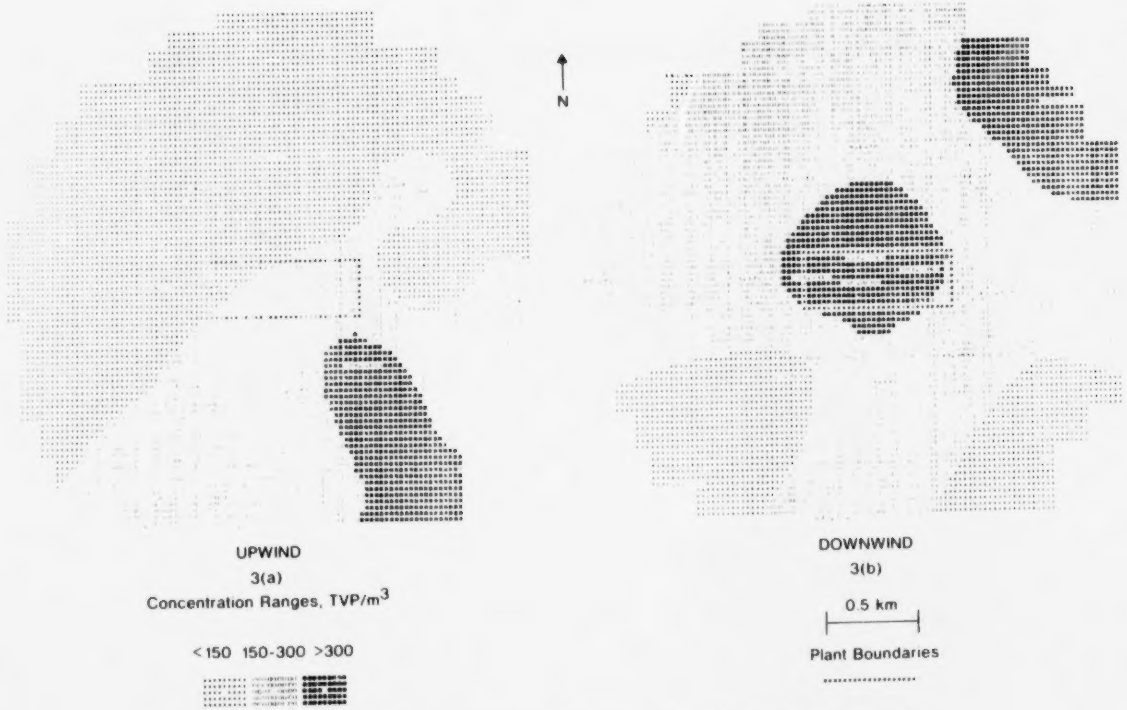

N
UPWIND
3(a)
Concentration Ranges, TVP/m3
<150 150-300 >300
DOWNWIND
3(b)
0.5 km
Plant Boundaries

Figure 6. Study Area Concentration Profiles for Total Viable Particles (TVP)

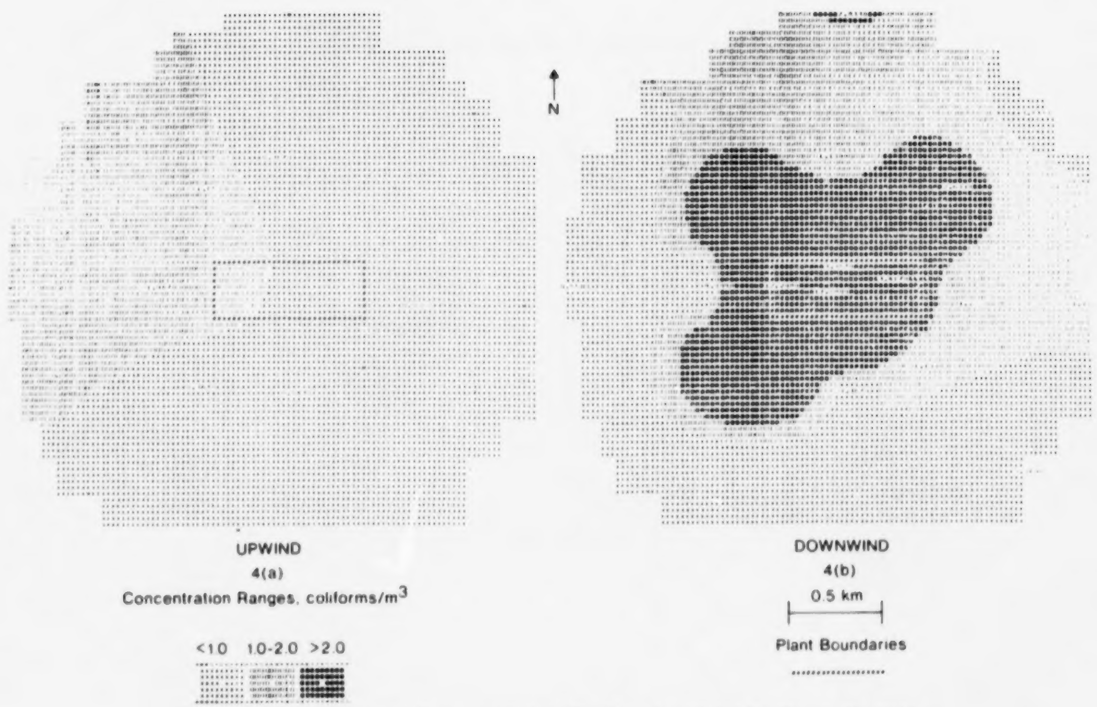

N
UPWIND
4(a)
Concentration Ranges, coliforms/m3
<1.0
1.0-2.0
>2.0
DOWNWIND
4(b)
0.5 km
Plant Boundaries

Figure 7. Study Area Concentration Profiles for Total Coliform Particles (TCP)

Exposure indices for total viable particles and total coliform were developed by combining the modeled upwind and downwind concentrations with the wind rose data for the study period as shown in Figure 5. The process used to accomplish this is as follows: First, for each household in the study area, an upwind and a downwind exposure index were predicted by SYMAP. Each household was then associated with the closest wind direction of Figure 5. The percentage of the time each household was upwind and downwind of the plant was calculated by assuming that each house is downwind from the plant if the wind is within a 135° arc directly across the study area from that house. For example, if a household has been associated with the northwest direction, winds from the east, southeast, and south place that house downwind of the plant. Winds from the southwest, west, northwest, north, and northeast place that house upwind of the plant. The house is, therefore, downwind of the plant 10.75% + 7.04% + 13.39%, or 31.8% of the study period and upwind 18.62% + 17.55% + 10.42% + 12.40% + 9.75%, or 68.75% of the study period.

The exposure index for each household is then calculated from Equation 4:

$$\text{Exposure} = (\text{UPEXP})(\%\ \text{upwind}) + (\text{DOWNEXP})(\%\ \text{downwind}) \qquad \text{(Equation 4)}$$

Where: Exposure = household exposure index for study period
UPEXP = household upwind exposure
% upwind = percent of study period house was upwind of the plant
DOWNEXP = household downwind exposure
% downwind = percent of study period house was downwind of the plant.

UPEXP and DOWNEXP are predicted by SYMAP for each household used in the analysis.

Two studies were carried out to check the accuracy of the process described above. First, the study-period wind direction distribution was compared to the wind direction distribution for sampling hours only. These two distributions were almost identical. This allows the combination of study-period wind data and exposure values with no error resulting from possible abnormal winds during sampling.

Second, a validation of SYMAP's interpolation accuracy was carried out. This was accomplished by dropping one of sites 5 through 12 at a time and having SYMAP predict a concentration at the missing site. This represents a worst-case analysis because at no point in the study area does SYMAP have to search farther for adjacent sampling sites than from one of sites 5 to 12 to the surrounding sampling points. The comparison between the actual and predicted concentration at sites 5 through 12 showed that SYMAP always interpolated an exposure index to at least within a factor of 2 under worst-case conditions. This is further confirmed by examining maps of downwind exposure when one of the 0.8 km downwind data sites was missing. These maps all showed the same pattern of elevated exposures into the community as is shown in Figure 6.

In addition to the study-period average exposure indices for total viable particles and total coliform, an exposure index for every 2-week Health Watch period for total viable particles was calculated. Total coliform was not used in the 2-week analysis because the data were all collected in the fall. In addition, the accuracy of combining subgroups of the data when the measurement is so close to the detection limit would be questionable. The process of developing 2-week exposure indices was the same as the study-period index. For each 2-week period, an upwind and downwind exposure index was calculated for each household. These indices were then combined with a wind direction distribution from the same 2-week period using Equation 4. This resulted in 16 exposure indices for each household in the study.

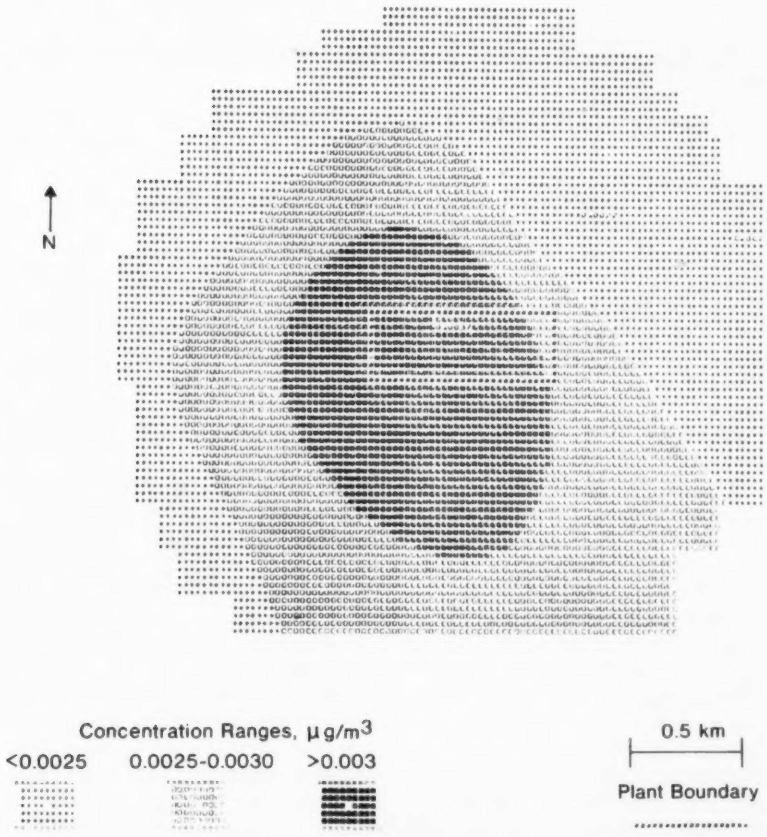


Figure 8. Study Area Concentration Profile for Airborne Sn

Analysis of Plant as an Emission Source

The calculation of household exposure indices for the nine nonviable pollutants was much more direct than for the viable measurements. SYMAP plots of nonviable indices represent study-period averages of the nonviable indices integrated for all wind directions. It was, therefore, only necessary for SYMAP to interpolate an exposure index for each household in the health study for each pollutant.

It is important to point out that all nonviable concentrations measured, with the exception of $SO_4^{=}$, were very low with respect to environmental health standards and Chicago averages for the same seasons. Chicago $SO_4^{=}$ data were not available, so no comparison could be carried out.

Distance-Concentration Relationships. All 20 nonviable and two viable pollution indices were modeled by SYMAP to identify which pollutants could be related back to the sewage treatment plant as an identifia-

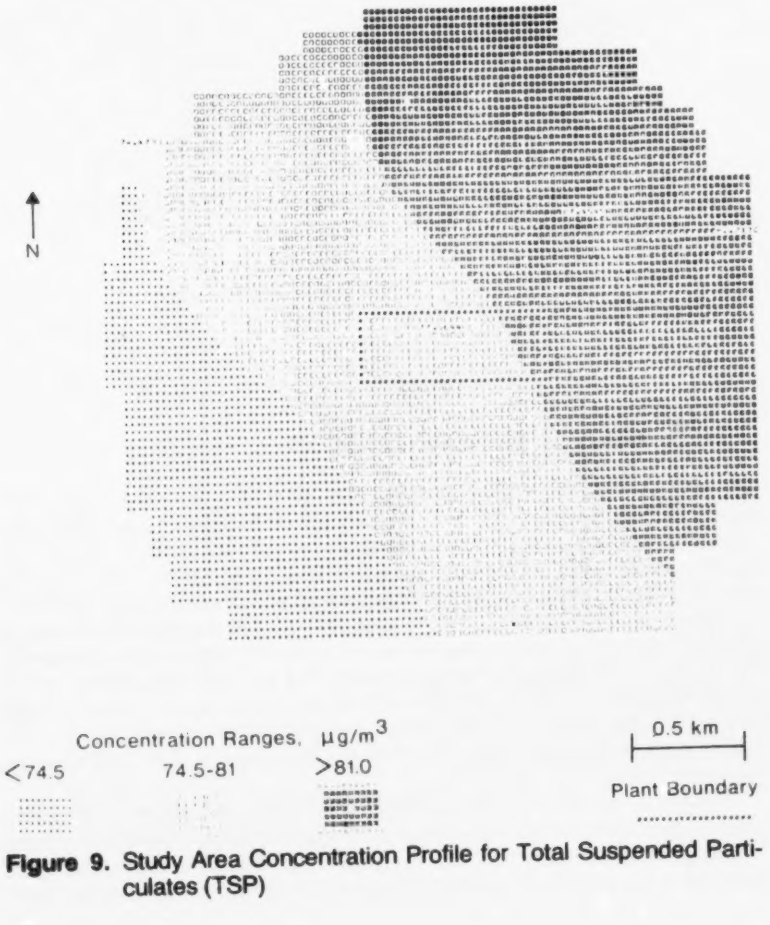


Figure 9. Study Area Concentration Profile for Total Suspended Particulates (TSP)

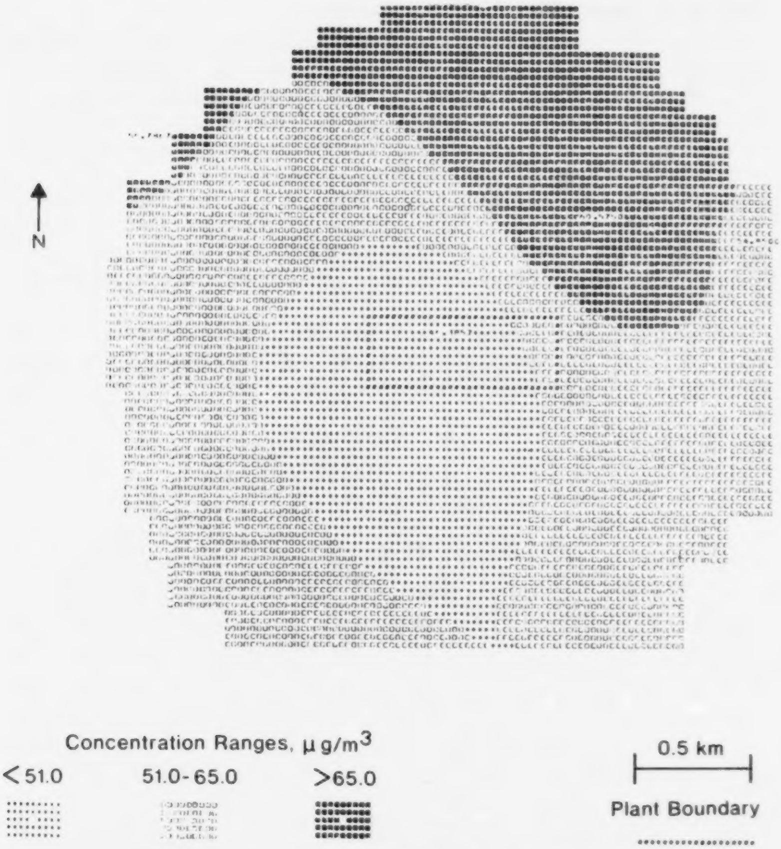


Figure 10. Study Area Concentration Profile for NO_2

ble source. For the viable indices, upwind and downwind maps were plotted (Figures 6 and 7). For the nonviable indices, integrated wind-direction maps as well as maps sorted by wind direction were plotted. Of all 22 indices, only total viable particles (Figure 6), total coliform particles (Figure 7), and possibly tin (Figure 8) identify the plant as a source.

However, this pattern for tin is based on only 18 measurements above the detection limit, and so this relationship to the plant is quite tentative. Study-period average concentrations of TSP and NO_2 integrated for all wind directions is shown in Figures 9 and 10, respectively. A set of maps for TSP concentrations when winds were from the south, north, east, and west are shown in Figure 11. The major source of TSP was Chicago (south winds).

The total viable particle average concentrations show a decrease with distance from the plant. Table 18 shows that the downwind total viable particle concentration at the plant is greater than three times the upwind or background concentration. At 0.8 km downwind of the plant,

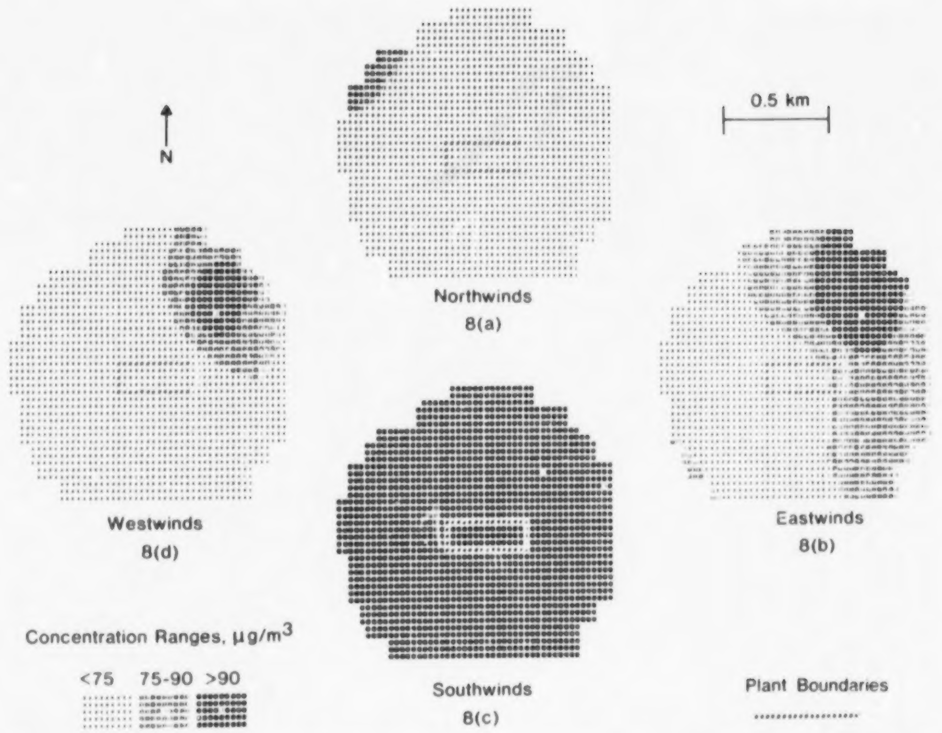


Figure 11. Total Suspended Particulate (TSP) Concentration Profiles by Wind Direction

the average total viable particle concentration is still 45% greater than the background concentration. The 1.6 km downwind average concentration is also higher than the background concentration.

The total viable particle upwind and downwind maps, Figure 6, shows that the plant contribution to the total viable particle air concentration extends farther than 0.8 km downwind of the plant. The 1.6 km downwind concentration is higher than the 0.8 km downwind concentration; however, this is partially the result of some other source or sources of total viable particles located near site 14 (Figure 4). Such a source or sources located near site 14 not only increase the downwind concentration at site 14 but also increase the 0.8 km upwind concentration at site 6. Removing site 14 and site 6 upwind from the analysis removes any complications encountered because of the other possible sources at site 14. The remaining sites show a clear pattern of the effect of the treatment plant on the surrounding community when they are downwind of the facility (Figure 12).

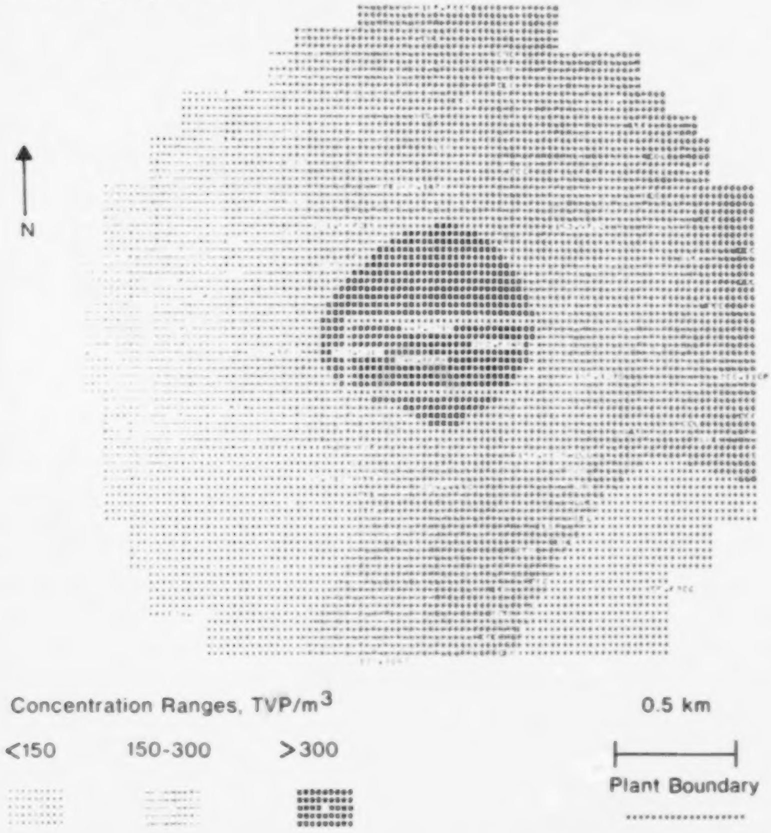


Figure 12. Study Area Concentration Profile for Total Viable Particles (TVP) Excluding Site 14 Downwind

Table 29 shows the four average position variables without samples collected at site 6 (when it was upwind of the plant) and site 14. The downwind concentrations are all higher than the background concentration and decrease with distance from the plant. Figure 12 shows the downwind study-area concentrations affected by the plant source only and supports this conclusion.

Table 29. Average TVP Concentrations by Sampling Position Without Sites 6 Upwind and 14 Downwind

Sampling site position[a]	Total viable particles No. of samples	Mean concentration (particles/m³)	Standard deviation (particles/m³)
0.8 km upwind	52	141	121
On-plant downwind	68	376[b]	339
0.8 km downwind	68	198[b]	155
1.6 km downwind	51	155	144

[a] Position relative to plant

[b] Significantly greater than the upwind value ($p < 0.05$)

A one-way analysis of variance was run to test the significance of the difference between the means of the four position variables. When run both with and without sites upwind and 14 downwind, the difference between position means is significant at the 0.05 level.

In order to determine which of the three downwind position means are significantly higher than background, t-tests were run comparing the 0.8 km upwind concentrations to the plant, 0.8, and 1.6 km downwind concentrations separately. These tests were run both with and without sites 6 upwind and 14 downwind. When all 20 downwind and eight upwind sites are included, the differences in concentration between 0.8 km upwind and all three downwind sites are significant at the 0.05 level. The same comparisons when run on the data without sites 6 upwind and 14 downwind show that the plant and 0.8 km downwind concentrations are significantly higher than background at the 0.05 significance level. The 1.6 km downwind concentration is not significantly higher than the 0.8 km upwind concentration at the 0.05 or 0.1 significance levels.

The total coliform concentration at the plant is six times greater than any of the other position concentrations (Table 18). Assuming the 0.8 km upwind concentration represents background conditions, it appears that the plant does add significant amounts of coliform to the air that passes over it. By the time the air reaches 0.8 km downwind of the plant, however, the coliform concentration returns to the background levels. The plots of the upwind and downwind coliform concentrations (Figure 7) confirms this. A one-way analysis of variance showed the variation in means of the coliform data to be significant at the 0.05 significance level.

The results from eight samples taken with the LVAS are shown in Table 22. The LVAS and Andersen sampler do not measure the same thing; therefore, the results cannot really be compared. Both the total coliform and fecal coliform concentrations indicate that the plant is contributing these organisms to the surrounding atmosphere but that this effect is no longer at a distance of 0.8 km from the plant. Relationships with other parameters cannot be tested due to the small number of samples collected.

The following conclusions appear to be warranted: 1) the effect of the plant on total viable particles is significant out to at least 0.8 km downwind and does not return to background until almost 1.6 km downwind; and 2) the effect of the plant on total coliform concentration is significant. However, because of the limited viability of coliform in air, the concentration returns to background 0.8 km downwind from the plant.

In order to thoroughly compare the differences between the means from all four positions, the Duncan multiple range test in conjunction with a one-way analysis of variance was used. The Duncan tests show when sites 6 upwind and 14 downwind are not included, that the plant measurements of total viable particles and total coliform are significantly higher than the other three position means at the 0.05 level of significance. Log transformations are commonly used for air pollution data because of extreme values. When the natural log of concentration of total viable particles is used, the Duncan test shows that the plant concentration is higher than the other three position concentrations and that the 0.8 km downwind concentration is higher than background at the 0.05 significance level.

Meteorology, Plant Operating Characteristics, and Concentrations. A second approach to the characterization of the plant as an emission source was a comparison between air quality measurements and sewage characteristics, meteorology, plant operating parameters, and interaction effects between these variables. The goal of this analysis was to develop a model to predict viable concentration in the study area based on meterology, sewage characteristics, and plant operating conditions. A second goal was to determine if the plant was a significant source of any nonviable pollution. When on-plant total viable particle concentrations were compared using regression analysis with plant operating characteristics (such as sewage throughput or air rate), or total aerobic bacteria in sewage concentrations, no obvious relationships were found. However, sampling locations 1 through 4 (Figure 4) were not always directly downwind. When the analysis is limited to those observations ± 22.5 from due east or west (sites 2 and 4), a rough association ($r = 0.68$, significantly different from zero at the 0.005 level) is evident (Figure 13). These concentrations reflect air passage across maximum tank surface areas. (The north-south distance is only 25% of the east-west distance.) The spread in the data could not be further explained by systematic differences in wind speed, temperature, or relative humidity. Total coliform also did not show any striking relationships with sewage concentrations or operating parameters.

Total viable particles and coliforms in air were compared using regression analysis with temperature, humidity, wind speed and direction, solar radiation, and ultraviolet radiation for the plant and 0.8 km upwind and downwind positions. No discernible relationships were found between total viable particle and coliform concentrations and humidity, temperature, solar radiation, UV radiation, or wind direction. In order to further delineate the effects of meterological conditions, a multiple

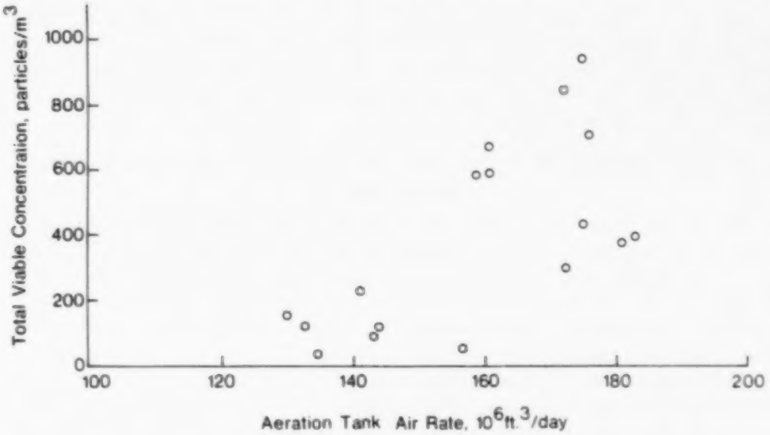


Figure 13. Total Viable Particle (TVP) Concentration Versus Aeration Tank Air Rate

regression was done with wind speed, temperature, and relative humidity as the independent variables and total viable particle concentration as the dependent variable. Due to the low r^2 of 0.11 (percentage of the variance explained by these three variables), these meterological parameters cannot be considered to have a significant effect on total viable particle concentration. Even less of the differences between total coliform concentrations can be explained by wind speed, temperature, and relative humidity ($r^2 = 0.048$) using this same method.

The TVP concentrations were correlated with the average NO_2, SO_2, and TSP concentrations measured on the same day. A significant correlation between NO_2 and TVP concentrations was found for TVP measured at the plant ($r = 0.64$, significantly different from 0 at the 0.02 level). No correlation was found at any other sampling locations or with either SO_2 or TSP at any location.

No relationships (regression analysis) were found between plant nonviable measurements and any plant operating or sewage characteristic. The off-plant sites B, C, D, and E were analyzed by comparing upwind and downwind measurements made at each site. No relationship was found between TSP, $SO_4{}^=$, $NO_3{}^-$, and any sewage or operating parameter. Sites C, D, and E are all 1.6 km away from the plant. Combining these three sites for the wind direction analysis also did not produce any relationship between a nonviable pollutant and a sewage characteristic or plant operating characteristic.

Even though a variety of trace elements were found in the sewage (Table 28) most are apparently not discharged into the air in sufficient quantities to be notable. The same was true for $NO_3{}^-$ and $SO_4{}^=$. The lack of correlation between operating parameters and any of the nonviable pollutants is somewhat puzzling, particularly in light of the fact that both sewage throughput and air rate independently varied by almost a factor of 2. Apparently the quantities of $SO_4^{=}$, NO_3^{-}, and trace elements which are aerosolized do not measurably contribute to the existing background concentrations. It may be that aeration tank surface area and air discharge velocity are more important factors for emission of pollutants to the atmosphere.

INTEGRATION OF HEALTH AND ENVIRONMENTAL DATA

Introduction

The major purpose of this study was to determine whether or not a sewage treatment plant is a health hazard to a community. This was investigated by integrating the environmental exposure data with the health data for the study population in the community. The environmental data provided exposure indices for total viable particles, total coliform bacteria, and nonviable pollutants (TSP, metals, and gases) for each household for the 8-month study period. The Health Watch data provided household illness and infection rates for the same period. The seroepidemiological survey provided the most valid incidence rates of infection, but for only a few selected viruses. Finally, the retrospective health questionnaire survey permitted the identification of persons potentially at high risk to the health effects of viable and nonviable pollution exposure.

A dose-response approach was taken in the analysis of exposure and health effects. Regression analyses were performed to determine if health effects increased with exposure, or if the two variables varied independently. Scatter diagrams were prepared to further examine the relationship between exposure and health effects.

Total Viable Particle Exposure and Self-Reported Acute Illness

Acute Illness Rates and Total Viable Particle Exposure. Total viable particle exposure indices for the 8-month study period were compared with acute illness rates for each of the 290 Health Watch households. Eight-month exposure indices were calculated with and without sites 6 (upwind) and 14 (downwind) since these sites reflected a source of total viable (downwind) particles other than the plant. The range and mean in particles/m^3 for the exposure indices using all sites were 86 to 265 and 155, respectively. The range and mean for the indices excluding sites 6 and 14 were 86 to 264 particles/m^3 and 158 particles/m^3, respectively. In relating illness rates to total viable particle exposure, it was necessary to limit the illnesses to those types which potentially had a causal association with viable particle exposure. With this in mind, the illness rates were based on self-reported (diary) acute illnesses equal to or greater than 1 day duration and were calculated for respiratory, gastrointestinal, eye and ear, skin, and total illnesses. The 290 8-month household total illness rates ranged from 0 to 71.43 and averaged 7.31 illnesses/1000 person-days of exposure.

Regression analyses of the 8-month household total viable particle exposure indices and the corresponding 8-month household acute illness rates were performed. No linear relationship ($p > 0.05$) was found for these variables with or without sites 6 (upwind) and 14 (downwind). This was true for the separate illness categories as well as all types of illnesses combined. All of the correlation coefficients were <0.1 and not significantly different ($p > 0.05$) from zero. Scatter diagrams of total illness rates and respiratory illness rates against total viable particle exposure indices (calculated both ways) did not reveal any apparent relationships missed by the regression analysis. The lack of correlation between 8-month total viable particle exposure and illness rates may be the result of an inadequate sample size (in terms of number of households), an unequal frequency distribution of household exposure indices in terms of not having enough households exposed at "low" or "high" levels of total viable particle concentrations, the inaccuracies in self-reported illness rates, the existence of more complex functional relationships between the health and exposure variables, or no relationship at all.

Temporal Acute Illness/Total Viable Particle Exposure Relationships

Regression analyses between illness and exposure were also performed on a 2-week averaging period basis. These periods correspond to the Health Watch data-collection periods. The same illnesses used for the total viable particle analyses discussed above were calculated as 2-week period rates. Not enough total viable particle measurements existed for the first data-collection period (April 3 to 16) so the analyses were performed for only the last 16 2-week periods. No linear relationships ($p > 0.05$) were found for the 2-week periods when analyzed separately or together for all types of illnesses or for respiratory illnesses only. Respiratory illnesses were considered separately since they represented a large proportion of the total illnesses reported.

In order to examine a possible lag effect between exposure and illness, a 2-week lag period analysis was carried out. This was accomplished by correlating a 2-week period's illness rates with the previous 2-week period's exposure indices. A 2-week period was the smallest lag period possible to analyze. Again, no linear relationship ($p > 0.05$) between 2-week illness rates and total viable particle exposure measured 2 weeks prior to the illness period was detected.

In addition to the explanations for lack of correlation provided in the previous section, it was also possible that the 2-week lag period was too long in terms of incubation period for most bacterial and viral agents possibly associated with these illnesses. It was also important to note that the 2-week exposure indices were much less reliable measurements than those based on the total study period.

Acute Illness Rates for High Risk Subgroups and Total Viable Particle Exposure

An attempt was made to examine the relationship between illness and exposure for various subpopulations potentially at high risk to the effects of total viable particle exposure. Age, chronic respiratory disease, chronic gastrointestinal problems, smoking, family composition (presence of young children), and length of residence in the study area were considered potential risk factors. Regression analyses between the 8-month illness rates (as separate categories and as total illnesses) and exposure indices were carried out controlling for each of these high-risk groups.

The acute illnesses defined above were used to calculate rates for persons within households belonging to a specific high-risk subgroup. A person-exposure index was taken to be equal to a person-household exposure index. The correlation coefficients for four age groups (0 to 12, 13 to 18, 19 to 59, and 59 years) did not reveal any linear relationships between illness and exposure. A similar finding was derived for the 70 people with chronic respiratory disease (chronic bronchitis, emphysema, or asthma). The correlation coefficients for persons with chronic gastrointestinal problems were not significantly different ($p > 0.05$) from zero. Regression analyses of smokers (current) and nonsmokers also resulted in correlation coefficients not significantly different ($p > 0.05$) from zero. Family composition was categorized as follows: 1) families with only one or two members (all adults); 2) families with youngest child age 0 to 5 years; 3) families with youngest child between 5 and 14; and 4) families with youngest child over 13 years old. All but one correlation coefficient ($r = 0.27$ for skin illnesses for families with youngest child between 5 and 14) were not significantly different ($p > 0.05$) from zero. Length of residence was considered in terms of less than 1 year, 1 to 5 years, 6 to 10 years, 11 to 20 years, and over 20 years of residence in the study area. All but one coefficient ($r = 0.39$ for skin conditions in the over 20 years of residence group) were not significantly different ($p > 0.05$) from zero. The correlation coefficients obtained for skin conditions for families with youngest child between 5 and 14 years old and for greater than 20-year residents are based on mean illness rates of 0.25 and 0.07 skin conditions/1,000 person-days of exposure, respectively, and are therefore of questionable importance.

In summary, regression analyses of acute illness and total viable particle exposure with consideration given to high-risk variables did not result in any significant linear relationships. Again, the lack of any apparent linear correlation between exposure and illness may be due to inadequate sample sizes, an inadequate representation of exposure levels, inaccuracy of the illness data, or the existence or nonexistence of more complex relationships. Because of the consistent lack of any significant relationships when each independent variable was considered singularly, any multiple regression analysis would also be of no significance.

Total Viable Particle Exposure and Infection Rates

Throat and Stool Specimens

As was reported earlier, 174 bacterial organisms were isolated from throat cultures of children 0 through 12 years of age. Throat bacterial infection rates were developed as follows:

$$\begin{array}{l}\text{throat bacteria infection} \\ \text{rate/1,000 person-days}\end{array} = \frac{\Sigma \text{ unique bacterial isolations} \times 1{,}000}{\begin{array}{l}\Sigma \text{ days present in study area for every} \\ \text{2-week data-collection period a} \\ \text{throat culture was received}\end{array}}$$

(Equation 5)

These rates were then compared to the 8-month total viable particle exposure indices. In Figure 14, the bacterial infection rates were plotted

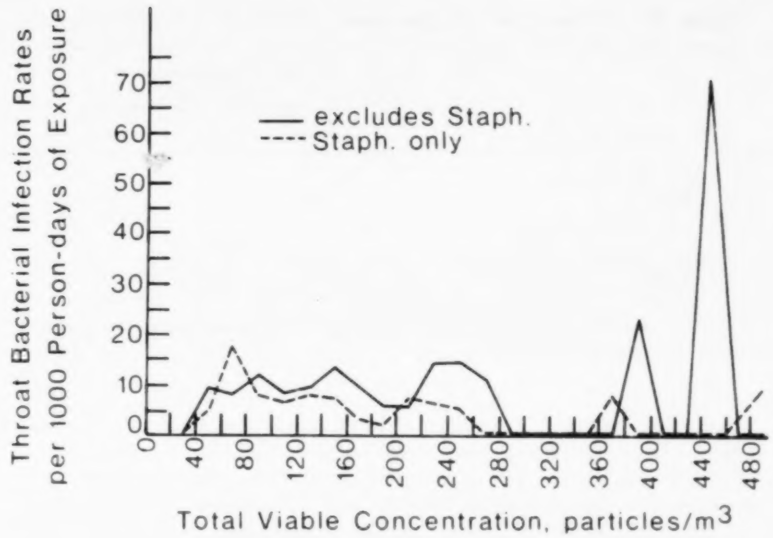


Figure 14. Respiratory Infection Rates Versus Total Viable Particle (TVP) Exposure

for *Staphylococcus aureus* and all other bacteria combined. *S. aureus* was specifically plotted because it is most frequently transmitted from person to person and is unlikely to be of environmental origin. Both rates of bacterial infection were unrelated to total viable particle exposure; the two distributions of infection rates were similar. Thus, there appears to be no dose-response relationship between viable particle exposure and bacterial infections. Regression analysis confirmed the lack of a linear relationship between infection rates and total viable particle exposure (correlation coefficient = 0.07).

Serosurvey

Analysis of virus infections was possible by comparison of the total viable particle concentration of household exposure with infections due to coxsackieviruses and echoviruses as determined serologically. Regression analysis of the initial virus antibody titers and total viable particle exposure indices was carried out for each of the coxsackieviruses and echoviruses. None of the correlation coefficients were significantly different ($p > 0.05$) from zero. Table 30 shows the number of sera tested which showed a fourfold rise in antibody and the number of sera tested in which a rise was not found for any of the five coxsackieviruses and four echoviruses tested. Also shown are the mean total viable particle exposure indices associated with each serological group. The total viable particle exposure was less for persons with no seroconversions (160) compared to those with at least one antibody rise to one of the types of

Table 30. Summary of TVP Exposure for Viral Seroconversions

	Total viable particle exposure (particles/m³)	
No. antibody rises/sera	Mean	Range
Coxsackie viruses B1-5		
0 (272)[a]	160	86-411
≥1 (46)	175	86-411
Echoviruses 3, 6, 9, 12		
0 (292)	163	87-411
≥1 (25)	145	86-392

[a] No. of sera tested indicated in parentheses

coxsackieviruses (175). A different pattern was observed for the echovirus conversions which suggested an inverse relationship between exposure and frequency of infection. The differences observed were not remarkable enough to suggest that the risk of infection was greater or less due to increased exposure to total viable particles.

Similar analyses were carried out for only those who were susceptible to the viruses under varying criteria for "susceptibility." Five different "susceptible" definitions were used: those with an initial titer of < 10, ≤ 10, ≤ 20, ≤ 40, and ≤ 80. In comparing the mean exposure index for those susceptibles who had experienced at least a fourfold rise against the index for susceptibles who had experienced less than a fourfold rise, no significant differences ($p > 0.05$) were seen for any of the "susceptible" groups for any of the viruses or virus groups.

Total Coliform Bacteria Exposure and Self-Reported Acute Illness

Regression analyses of total coliform bacteria exposure indices and corresponding acute illness rates were made for each household. The total coliform bacteria exposure indices cover a 12-week period since total coliform measurements did not begin until September 13. The range of the 290 household exposure indices (all sites) was 0.25 and 3.55 particles/m³ with a mean of 1.42 particles/m³. The illness rates used for this analysis were based on the same criteria described for the total viable particle analyses and correspond to the data-collection periods covered by the exposure index (September 18 to November 26). No linear relationship was found for respiratory illnesses or for all illnesses combined.

Exposure to TSP, Metals, and Gases and Self-Reported Illness

The 8-month exposure indices developed for NO_2, SO_2, TSP, NO_3^-, $SO_4^=$, V, Mn, Cu, and Pb represent an adequate characterization of the study area exposure for those nonviable constituents. Although these constituents were found not to be associated with the sewage treatment plant, regression analyses between exposure and illness were performed to search for an association between these constituents and health.

The illness rates used in these regression analyses included chronic conditions and conditions lasting less than 1 day. No linear relationship ($p > 0.05$) was found between the household illness rates and corresponding household exposure indices for any of the nine constituents. This was the case for all illnesses combined as well as for the separate illness categories (respiratory, gastrointestinal, skin, etc.). Scatter diagrams of the illness rates and corresponding exposure indices also did not reveal any apparent linear relationships.

DISCUSSION

MR. LINDAHL: Is it not true that the design of this particular plant is different from every other aeration plant in the world, and that this particular rate of aeration or design of aeration facility is different from any other in the country and the world?

DR. LUE-HING: May I answer that one?

MR. POLONCSIK: Please.

DR. LUE-HING: As far as I know, this is a basic design and the rates are comparable. I am not aware of any difference. The rates vary because the plates are older.

DR. DEAN: I think there is more information in your paper due to performance. I mean in this sense, most of the work that you did assumed that you had the data for the distribution. It is quite obvious from the data that you did not have a normal distribution of bacteria or viruses. There is a tendency to be abnormal, from what I can tell from the standard deviations.

If this is true, and it is very easy to check, you are going to get a different interpretation if you will go the way of log normal distribution. It will not cost any more. Your suggestion that certain differences are significant may be erroneous because the evidence is based on a normal distribution.

MR. SCHEFF: I am not the statistician, but we did do log transformations of all the data and we found no different patterns. I don't believe we stated that we found any differences that were statistically different. Maybe there was one or two statistically, but that would be expected in a large number of analyses. I don't think we put anything behind the differences.

DR. DEAN: The only part that would be useful would be in estimating the power. How big a difference would there have to be to figure it out at all? Then you will get a better estimate of the power.

DR. FLIERMANS: I have a question and then a comment. Are the trends that you saw for the respiratory illness a common phenomenon?

DR. NORTHROP: The season that we looked at was through November, that is, after school begins in September, and you begin to see an increase in the respiratory illness. What we did not see, that I might have expected, was an increase in gastrointestinal illness at the end of the summer. I think the epidemiology of gastrointestinal disease associated with infectious enteric agents isn't classical like it was a number of years ago. Immunizations and different social patterns have changed that.

DR. FLIERMANS: But let me make a comment relative to the kinds of things that you see with visionalosis. This is the same kind of thing that you have observed. We know that the mouth would not survive without tap water for an extended period of time. Maybe we are looking at the wrong end of the individual. Maybe we ought to look at the respiratory end and some of the organisms associated there. You have many situations where the organism can be transported.

DR. NORTHROP: Well, in terms of *Legionella*, we are doing an evaluation of the material that we have. That is in progress, so I will be able to specifically relate to that later. Transmissibility of *Legionella* is unestablished for man. It comes from the environment to man and it is not clearly understood.

DR. FLIERMANS: I think the CDC has a good body of evidence of inhallation in the type of situations where legionelosis is contracted by that kind of exposure, which to me becomes very important if you are talking about aerosols.

DR. NORTHROP: Correct. That is what we are trying to establish now. In terms of households, one member of a family acquiring it in household transmission, I would not expect that.

DR. FLIERMANS: Yes, there is no evidence of transmission.

DR. ANDELMAN: It seems to me that there are two obvious marked differences between the results of your study and the previous one. One is that you did not find any obvious health effects. The second is, by using your personal exposure index, that you did indeed obtain a correlation with wind direction. That seemed the logical thing to do. I am wondering if, perhaps, you tried also to do as the previous investigation did. Just look at the question of proximity as an alternative.

MR. WADDEN: Indeed we did look at this distance from the plant to see how good our exposure index was. We didn't see any differences as far as we now can tell. This is perhaps not unexpected because if you look at patterns, it is reasonably centered around where the plant is and that's true. But we did look at that.

I would like to expand a little on another point, which was that we did not find the kinds of results that some other people found important. I think it is well to remember that the kinds of concentrations we were looking at were much lower, usually, than what other people have seen. I have seen this data, and it had much higher concentration. Indeed, that was a problem with our monitoring because we expected a much higher initial concentration than we were able to receive.

DR. GERBA: I have two questions. I wonder if your lower concentration may be related to something like open air factor where it has been absorbed in captured aerosol disposed in the country versus in the city. Maybe viral fallout is more rapid in the captured aerosols in the city rather than the country. This may be one thing to consider when you are studying an industrialized area. The organism's survival time in the aerosol may be much less in the city. Maybe Dr. Spendlove could comment on open air background.

I have one other question, that is related to how much confidence you can really put in your antibody data, especially with the aerosols. I make special reference to the study on the antibody response in adults. They were studied over a period of a year and they had become, during the course of a year, exposed several times with viruses, but no antibody response occurred in those individuals. This was a study over some 30 to 40 different adults. How much faith should we really put in the antibody data?

DR. NORTHROP: I think our serology is probably the most solid bit of health information we have. Those are neutralizing antibody levels that are the basis of the titers reported here and the basis for the seroconversions. I think that is something that really needs a lot of investigation. Serologically, it is my understanding that after a few years of age, 90% of the populations will have it. Therefore, you would have to look at a very young population prospectively with exposure information.

Just to look at a population such as we had, would not be justifiable with the current state of the art. The Norwalk agent, which is another associated agent in the feces and diarrhea, is a different type of agent and hopefully could be used in the kind of study that is conducted here. This, in addition to *Legionella*, is something we are looking at.

DR. SPENDLOVE: The concentration is not what I suspected. I suspect that perhaps this will be associated with the other studies.

MS. HOLDEN: I am not sure we can say that, and that is why I did the nonviable pollutant/viable pollutant correlations. Maybe you can tell us what pollution factors have been associated with decreased numbers. It is definitely not associated with total suspended particulates or SO_2. Unfortunately, we had no carbon monoxide or carbon dioxide measurements.

DR. SPENDLOVE: I suspect that SO_2 will have some effect.

MS. HOLDEN: No, unfortunately, and I should have mentioned it. We only had about 12 sampling days on which we did nonviable and viable together on the same day. So that makes that correlation a lot less reliable. However, we were not in the city. That's an additional factor.

Epidemiological Study of Wastewater Irrigation in Kibbutzim in Israel

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ABSTRACT

A retrospective epidemiological study was carried out from 1977 to 1979 in Israel on the association between enteric disease incidence and effluent irrigation in 83 kibbutzim (cooperative agriculture settlements) with a total population of 41,000. We collected medical data from patient records at each kibbutz's medical facilities. The medical data collection consisted of 24 defined diseases, laboratory or clinically confirmed, about 50% of which were of the enteric disease group. The second group consisted of nonenteric diseases which served as a control. Environmental data was collected by means of a questionnaire filled out on site with the aid of the kibbutz coordinator. The preliminary results reported in this paper are based on data from a study of 36 kibbutzim with a population of about 14,000.

The research reported was divided into two categories:

- 13 kibbutzim which practiced 2 consecutive years of using effluent sources for irrigation at least part of the year and an additional 2 consecutive years in which only noneffluent water sources were used for irrigation
- 23 kibbutzim, 12 of which used effluent sources for irrigation in addition to noneffluent sources. The other 11 kibbutzim used only noneffluent sources for irrigation. The primary means of irrigation used by the kibbutzim was the sprinkling system.

In the first group, we compared total enteric disease incidence during the 2-year effluent irrigation period to the enteric disease incidence during the noneffluent irrigation period. In the second group, we compared the enteric disease incidence in the kibbutzim using effluent irrigation with the enteric disease incidence in the kibbutzim using only noneffluent irrigation sources.

The results were analyzed according to the age groups of the population, the irrigation season, and other environmental factors. Inspection of overall incidence of enteric disease incidence in the first group (for the different age groups) does not appear to show evidence of the association between the effluent and noneffluent irrigation years at the same kibbutz. In an analysis of various environmental factors in the second group, in no case was there any apparent difference between effluent-irrigating and noneffluent-irrigating kibbutzim.

Additional in-depth analysis for the entire group of 83 kibbutzim is underway. Therefore, no final conclusions can be drawn at this time.

The use of wastewater effluent in agriculture is becoming common in many areas of the world, including the United States, as a means of increasing water resources through recycling. This utilization is also regarded as a strategy for reducing pollution of surface waters.

Israel suffers from a severe shortage of water resources; over 95% of the available water supplies are currently being utilized. This situation has led to the extensive use of wastewater in Israel for irrigation of various crops and for enrichment of fishponds. Irrigation methods used in Israel today are sprinkler and drip. About 90% of the total irrigation is done by sprinkling. The amount of sewage potentially available for exploitation in Israel is about 200 million m^3/year. About 20% was recycled in 1979, with the area of land irrigated with wastewater reaching 8,000 hectares.

The extensive use of effluent in agriculture creates a potential health hazard for field workers and the population adjacent to the fields. Humans may possibly be infected by aerosols containing pathogenic bacteria or viruses by inhalation of particles of 0.5-5.0 μm which penetrate the respiratory system. The larger droplets, however, can be trapped in the upper respiratory system, including the nose and larynx, and from there they may reach the digestive tract. Other modes of transport of pathogens from areas irrigated with wastewater are by direct contact with irrigation workers, contaminated crops, and fomites.

Hickey and Reist (1) reported that pathogenic bacteria may be transported in aerosols from sewage to humans. In a later survey, Clark, et al (2), emphasized the potential risk to sewage workers of enteric diseases from occupational exposure. Adams and Spendlove (3) isolated microorganisms from aerosols at a distance of 1200 m downwind from a sewage treatment plant. However, there is little proof of the degree of health risk from aerosolized sewage.

The Environmental Health Laboratory of The Hebrew University-Hadassah Medical School has succeeded in isolating coliforms at a distance of 350 m and salmonella at a distance of 60 m downwind from the wastewater irrigated fields (4). Also, they succeeded in isolating enteroviruses at a distance of up to 100 m downwind from effluent irrigation (5).

One of the first retrospective epidemiological studies on the possible health risks associated with sprinkler irrigation with wastewater was carried out by our group in Israel (6). In this study, the authors were able to show that in 77 kibbutzim (agricultural cooperative settlements) practicing mainly sprinkler irrigation with undisinfected oxidation pond effluent that the incidence of typhoid fever, salmonellosis, shigellosis, and infectious hepatitis was two-four times higher than in 130 control kibbutzim not practicing any form of effluent irrigation.

The researchers themselves pointed out that from this study they could not provide definite proof that the added health risk in effluent-irrigating kibbutzim was associated with the dispersion of pathogenic microorganisms by aerosols, because a number of pathways of infection other than aerosols existed, such as direct contact via clothing or bodies of sewage irrigation workers or exposure to the crops.

This preliminary survey also had serious methodological constraints in that the investigators based their findings solely on official communicable disease reports which were submitted to the Ministry of Health as required by law. These requirements do not include listing of all relevant diseases, and there are known serious defects in such reporting methods. Therefore, no conclusive findings may be based on this report. Consequently, new research, based on primary medical and environmental data collected at each kibbutz, as proposed by this project, is necessary to confirm or rebut the findings of the initial retrospective study of wastewater irrigation in kibbutzim.

Working Hypothesis

In this retrospective study it is proposed to study the difference in enteric disease incidence by comparison of the disease rate in accordance with the following categories (Table 1).

Definitions of Categories:

- "Effluent-Irrigating Kibbutzim" (A and B) are those kibbutzim which utilize both their own sewage and/or that of nearby urban settlements for effluent irrigation and are assumed to be either exposed to aerosolized sewage and/or to other pathways of transmission such as food and body contacts or transmission by fomites.
- "Noneffluent-Irrigating Kibbutzim" (C) are those which do not practice effluent irrigation (but do utilize other sources of water) and are not exposed to aerosolized sewage from effluent-irrigated neighboring fields at a distance of up to 5 km from residential areas.
- "Exposed to (Sewage) Aerosols" (A) are those kibbutzim which are within 800 m from sewage-irrigated fields and their residential area is within the aerosol plume at least 70% of irrigation time.
- "Not Exposed to Aerosols" (B) are those kibbutzim practicing wastewater irrigation but where the residential area is at least 1.5 km from effluent-irrigated fields and is predominantly upwind i.e., 70% of the time, or where the method of irrigation is not by sprinkler irrigation.
- "Effluent in Fishponds" (D) are those kibbutzim which utilize their own sewage and/or that of adjacent settlements for enrichment of their fishponds. Some of these kibbutzim use the fishpond water after drainage for crop irrigation.

Using the above categories, we will examine the following working hypothesis:

- The enteric disease incidence rate in the irrigation season in effluent-irrigating kibbutzim (A_2, B_2) is significantly higher than in noneffluent-irrigating kibbutzim (C_2) i.e. A_2 and $B_2 > C_2$. On the other hand, we do not anticipate an increased enteric disease incidence rate in the nonirrigation season, $A_1 = B_1 = C_1$.
- The control disease incidence rate in effluent-irrigating kibbutzim (A and B) will not be any different from the rate in the noneffluent-irrigating kibbutzim (C) regardless of the irrigation season, i.e. A = B = C.

Table 1. Classification of Kibbutzim by Use of Effluent

Season	Type of kibbutz			
	Effluent-irrigating kibbutzim		Non effluent-irrigating kibbutzim	Kibbutzim utilizing effluent in fishponds
	Exposed to Aerosols	Not Exposed to Aerosols		
Nonirrigation	A_1	B_1	C_1	D_1
Irrigation	A_2	B_2	C_2	D_2

- We anticipate that in the irrigation season the enteric disease rate will be higher for effluent-irrigating kibbutzim which use sprinklers and are exposed to aerosols (A_2) than for effluent-irrigating kibbutzim not exposed to aerosols (B_2) i.e. $A_2 > B_2$.
- If the rates of enteric disease in kibbutzim utilizing sewage for fishpond enrichment (D) is greater than those kibbutzim which are noneffluent- irrigating kibbutzim (C) ($D > C$), then it is possible to conclude that the reason is associated with the sewage in fishponds and the pathogen spread is by the direct contact with fishpond workers or by contact with or eating of polluted fish.

The kibbutz in Israel is a good model which allows us to thoroughly investigate the above hypothesis. There are many kibbutzim which use sprinkling irrigation and in which the main sewage treatment is non-disinfected oxidation ponds. In contrast, there are other kibbutzim which neither use effluent nor use sewage for fishponds. In each kibbutz there is a clinic staffed with a nurse and serviced by a physician. In addition, there are regional laboratories which perform routine communicable disease examinations for the kibbutzim. Another advantage is the high level of consciousness of the kibbutzim in health matters as well as their capability to record the environmental and medical data and their willingness to cooperate with a research effort of this kind.

Materials and Methods

There are 224 established kibbutzim in Israel which have a total population of 93,000. Due to budgetary and time limitations, we selected 83 kibbutzim for study.

The selected kibbutzim fell into four categories:

- 30 use effluent for irrigation and do not have fishponds; the total population is about 17,000
- 30 do not use effluent for irrigation and do not have fishponds; the total population is about 15,500
- 10 use effluent only for fishponds; the total population is about 5,000
- 13 used effluent sources for irrigation for at least part of the year for 2 consecutive years and another 2 consecutive years in which only noneffluent water sources were used for irrigation; the total population of the switched categories group is approximately 4,300.

Our study is based on retrospective data collected from several sources:

- *Personal medical records* of kibbutzim populations. The data was culled from these records for the period January 1, 1974 to December 31, 1977. Of the 24 diseases chosen, about half of them were enteric diseases which could be wastewater borne and the other half were control diseases. A list of the selected diseases appears in Table 2.
- *Interviews*. These were conducted with the agricultural managers of the kibbutzim to obtain environmental and demographic data such as use of effluent, volume of effluent used and treatment of same, methods of irrigation, the size of sewage-irrigated tract and type of crops, and the distance of the tracts from the fields to the communal dining halls.
- *Meteorological data*. Retrospective data was collected from the

Table 2. Selected Diseases from Kibbutz Clinic Patient Records

Enteric diseases	Control diseases
Typhoid fever	Measles
Paratyphoid	Chickenpox
Other *Salmonella* infections	Accidents
Bacillary dysentery	Rubella
Gastroenteritis	Mumps
Aseptic meningitis	Pneumonia
Infectious hepatitis	Bronchitis
Pathogenic coli; urinary tract infections	Upper respiratory infections
Food poisoning (bacterial)	Streptococcal throat infections
Fever of unknown origin	
Coxsackievirus infection	
Parasitic infections	
Amebiasis	
Leptospirosis	

Meteorological Service which collected data from 55 stations dispersed throughout the country.

Results

Stage I: Kibbutzim which switched categories

Tables 3 through 5 present the results of the analysis of those kibbutzim which switched categories from effluent irrigation to noneffluent irrigation or vice versa. Of the 13 kibbutzim studied, two had to be dropped due to insufficient data, reducing the total population to 3,950. From Table 3 no apparent difference in the enteric disease rate could be detected between a wastewater- and nonwastewater-irrigation period. In addition to disease rate/1,000, we calculated the ratio of enteric disease incidence to total disease incidence. The rates and ratios for the total group studied are presented in Table 3 and a breakdown by kibbutz is presented in Table 4. It should be noted that influenza is included in Tables 3 and 4, but parasitic infections, amebiasis, and leptospirosis are not included.

Based on the calculated ratio for each year, for each kibbutz we ranked each year's ratio from 1 to 4 (from low to high). The sum of the ranks for kibbutz equals 10 (1 + 2 + 3 + 4). We then summed the ranked

Table 3. Comparison of Disease Incidence in Kibbutzim with Sequential Two Year Periods of Effluent and Non-Effluent Irrigation (Switched Category)[a]

	2 years of noneffluent irrigation		2 years of effluent irrigation	
	Enteric disease	Control disease	Enteric disease	Control disease
No. of episodes	623	1,681	789	2,286
Rate/1,000	158	426	200	579
Ratio of enteric to total diseases	0.270	—	0.257	—

[a] Total population of the 11 kibbutzim is 3,949

numbers for all 11 kibbutzim for the effluent irrigation years and the noneffluent irrigation years. According to the null hypothesis, the sum of the ranked numbers should be equal to 55 (that is, $\frac{11 \times 10}{2} = 55$) for each category. Table 5 summarizes this form of analysis and shows that only in the age group 0 to 4 years is there an apparent excess of enteric disease for effluent irrigation years.

Table 4. Ratio of Enteric to Total Disease Incidence for Various Age Groups in Effluent-Irrigation Years and Noneffluent-Irrigation Years During The Irrigation Season Particular to Each Kibbutz (Switched Category)
(First and Second Year Respectively)

		Age group (years)							
		All ages		18+		5-18		0-4	
Kibbutz Code number	Year	Effluent-irrigation years	Non-effluent-irrigation years	Effluent-irrigation years	Non-effluent-irrigation years	Effluent-irrigation years	Non-effluent-irrigation years	Effluent-irrigation years	Non-effluent-irrigation years
1	1	.28	.40	.36	.33	.21	.50	.30	.37
	2	.15	.17	.27	0[a]	.20	.23	.06	.15
2	1	.21	.21	.67	.33	.06	.13	.17	.24
	2	.65	.38	.82	.57	.71	.13	.56	.37
3	1	.15	.29	.40	.33	.06	.40	0	0
	2	.15	.06	.33	.20	.07	.11	.17	0
5	1	.63	.16	.20	.33	0	.02	.71	.28
	2	.33	.60	.21	.44	0	.06	.40	.78
6	1	.06	.23	.03	.22	0	.16	.13	.25
	2	.09	.40	.02	.33	.04	.32	.21	.48
7	1	.33	.31	.36	.09	.37	.33	.30	.33
	2	.42	.24	.32	.13	.42	.22	.46	.28
8	1	.25	.54	.33	.08	0	0	.60	.60
	2	.52	.83	.67	.67	.10	.67	0	.93
10	1	.47	.25	.53	.42	.22	.13	.53	.13
	2	.27	.18	.35	.40	.17	.10	.29	.11
11	1	.08	.07	.04	0	.06	.09	.17	.07
	2	.40	.09	.28	.13	.33	.10	.52	0
13	1	.23	.19	.13	.38	.23	.07	.43	.10
	2	.32	.24	.41	.16	.30	.32	.30	0
14	1	.47	.29	0	.40	.33	0	0	0
	2	.22	.36	.08	0	0	0	0	.78

[a] Where zero is indicated, a ratio could not be calculated because one of the numbers was zero

Stage II: Effluent-irrigating versus noneffluent-irrigating kibbutzim

This primary analysis covers only 23 kibbutzim with a total population of 9,148. Of these, 12 kibbutzim were effluent-irrigating and had a population of 4,963 and 11 were noneffluent-irrigating with a population of 4,185.

The results of the preliminary analysis of incidence is presented in Tables 6 through 13. In no case was there any apparent difference between effluent-irrigating and noneffluent-irrigating kibbutzim. This includes groupings by different age groups (Table 10), by proximity of residential areas to effluent-irrigated areas (Table 11), by size of effluent-irrigated tracts (Table 12), and by type of resident (Table 13). In most cases the disease rates/1000 as well as ratio of enteric disease to total disease are compared.

Table 5. Total Sum Rank Numbers Assigned to Ratios[a] of Enteric to Total Disease Incidence for Various Age Groups in Effluent-Irrigation Years and Noneffluent-Irrigation Years During the Irrigation Season (Switched Category)

	Age group (years)			
	All ages	18+	5-18	0-4
Effuent-irrigation years	58	59	52	63
Noneffluent-irrigation years	53	52	59	48

[a] Ratios are based on Table 4

Table 6. Comparison of Total Number of Individuals Ill One or More Times with Enteric or Control Diseases During the Study Period in Effluent- and Noneffluent-Irrigating Kibbutzim (Stage 2)

Type of kibbutz	Enteric diseases	Control diseases	Total residents[a]
Effluent			
No.	1,644	3,031	4,963
Rate[b]	331	610	—
Noneffluent			
No.	1,691	2,699	4,185
Rate[b]	404	644	—

[a] Total residents includes ill and nonill population
[b] Rate/1,000 residents

Table 7. Comparison of Total Incidence of Enteric and Control Diseases for Effluent- and Noneffluent-Irrigating Kibbutzim (Stage 2) (Based on Clinical Diagnosis and Lab Conformation)

Type of kibbutz	Enteric diseases	Control diseases	Total incidence
Effluent			
No.	3,132	10,395	13,527
Rate[a]	631	2,094	2,725
Ratio[b]	0.23	—	—
Non-effluent			
No.	3,730	11,296	15,026
Rate[a]	891	2,699	3,590
Ratio[b]	0.25	—	—

[a] Rate/1,000 residents
[b] Ratio is quotient of incidence of enteric diseases to the total incidence

The analysis of the age groups as shown in Table 9 indicates a similar distribution of population in both effluent-irrigating and noneffluent-irrigating kibbutzim. The percentage of children in the age group 0 to 4 in noneffluent-irrigating kibbutzim is slightly higher (4%) than the same age group in effluent-irrigating kibbutzim.

Table 8. Comparison of Total Incidence of Enteric and Control Diseases for Effluent- and Noneffluent-Irrigating Kibbutzim (Stage 2) (Based on Positive Laboratory Results Only)

Type of kibbutz	Enteric diseases	Control diseases	Total positive incidence
Effluent			
No.	890	1,291	2,181
Rate[a]	179	260	439
Ratio[b]	0.41	—	—
Non-effluent			
No.	796	867	1,663
Rate	190	207	397
Ratio[b]	0.48	—	—

[a] Rate/1,000 residents

[b] Ratio is quotient of incidence of enteric diseases to the total incidence

Table 9. Age Distribution in Effluent- and Noneffluent-Irrigation Kibbutzim (Stage 2)

Type of Kibbutz	Age group (years)				
	0-4	5-9	10-18	18+	Unknown
Effluent					
No.	398	511	727	3,193	134
%	8.0	10.3	14.6	64.3	2.8
Noneffluent					
No.	489	416	523	2,536	221
%	11.7	9.9	12.5	60.6	5.3

Table 10. Comparison of Total Incidence of Enteric and Control Diseases for Various Age Groups In Effluent- and Noneffluent-Irrigating Kibbutzim (Stage 2)

Type of kibbutz	Age groups (years)							
	0-4		5-9		10-18		18+	
	Enteric	Control	Enteric	Control	Enteric	Control	Enteric	Control
Effluent								
No.	1,004	2,978	355	1,912	311	1,618	1,389	3,764
Rate[a]	2,522	7,482	694	3,741	427	2,225	435	1,178
Ratio[b]	0.25	—	0.16	—	0.16	—	0.27	—
Noneffluent								
No.	1,497	4,399	354	1,936	369	1,492	1,397	3,248
Rate[a]	3,061	8,995	850	4,653	705	2,852	550	1,280
Ratio[b]	0.25	—	0.16	—	0.20	—	0.30	—

[a] Rate/1,000 residents

[b] Ratios is quotient of incidence of entire diseases to the total incidence

Table 11. Comparison of Total Incidence of Enteric and Control Diseases According to Distance of Effluent Irrigation Fields from Communal Dining Halls (Stage 2)

	Distance			
	Up to 400 m		401-800 m	
	Enteric	Control	Enteric	Control
No.	1632	5293	1149	3907
Rate[a]	902	2927	952	3239
Ratio[b]	0.24	—	0.23	—

[a] Rate/1,000 residents
[b] Ratio is quotient of incidence of enteric diseases to the total incidence

Table 12. Comparison of Total Incidence of Enteric and Control Diseases According to Size of Effluent-Irrigated Tract (Stage 2)

	Size of tract (ha)									
	Up to 5		5.1-10.0		10.1-50.0		50.1-100.0		100.1 +	
	Enteric	Control	Enteric	Control	Enteric	Control	Enteric	Control	Enteric	Control
No.	750	2,290	434	1,393	277	875	73	178	1,453	5,130
Rate[a]	1,020	3,116	1,578	5,065	734	2,321	608	1,483	834	2,976
Ratio[b]	0.25	—	0.24	—	0.24	—	0.29	—	0.22	—

[a] Rate/1,000 residents
[b] Ratio is quotient of incidence of enteric diseases to the total incidence

Table 13. Comparison of Total Incidence of Enteric and Control Diseases According to Type of Resident for Effluent- and Noneffluent-Irrigating Kibbutzim (Stage 2)

Type of kibbutz	Type of resident							
	Members and candidates		Children (below 19 years)		Temporary (volunteers)		Others Included	
	Enteric	Control	Enteric	Control	Enteric	Control	Enteric	Control
Effluent								
No.	1,354	3,821	1,618	6,199	26	66	97	200
Rate[a]	465	1,337	1,036	3,971	187	474	348	719
Ratio[b]	0.26	—	0.21	—	0.28	—	0.33	—
Noneffluent								
No.	1,324	3,361	2,092	7,265	120	202	178	407
Rate[a]	613	1,557	1,589	5,520	460	808	515	1,179
Ratio[b]	0.28	—	0.22	—	0.37	—	0.30	

[a] Rate/1,000 residents
[b] Ratio is quotient of incidence of enteric diseases to the total incidence

Discussion

The results presented here represent a preliminary analysis of only one-third of the population under study, and it is therefore not possible to draw any conclusions at this stage.

Among the 11 kibbutzim which switched categories from effluent irrigation to noneffluent irrigation there were generally no apparent differences in disease rates between the two periods. However, according to a ranking procedure of analysis there seems to be some indication of excess enteric disease incidence in the age group 0 to 4 years in effluent-irrigating kibbutzim.

In another analytical approach that uses the binomial test for the above kibbutzim, Pahren (7) showed a significantly higher probability of enteric disease during the effluent irrigation season. This was true for the overall population but not for a specific age group.

The preliminary analysis of the 23 kibbutzim did not reveal any apparent differences in enteric disease incidence between those practicing effluent irrigation and those not practicing.

Additional in-depth analysis with further breakdown is required for the total population before any conclusions can be drawn. Even when our analysis is complete, we must take into account the methodological problems associated with retrospective studies of this type. For example, in the process of conducting this study we discovered that disease data on volunteers and temporary residents is generally not recorded. This means that critical data is absent from this analysis. It is our feeling that such groups of previously unexposed people are the most susceptible to change in health status and could provide critical information as to the degree of risk associated with wastewater irrigation during short periods of exposure.

Many of these methodological problems can be overcome in the planned prospective study to be supported by the U.S. EPA. In that study, special attention will be paid to the close follow-up of volunteer groups, with particular emphasis on determination of whether such groups display immunological susceptibility even though they do not show signs of clinical disease.

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DISCUSSION

DR. CLIVER: I wonder if you could tell us why you categorized influenza as an enteric disease?

MR. FATTAL: We considered influenza as an enteric disease because it was included in the enteric disease group in the first retrospective study. However, in our study, we did not differentiate between laboratory confirmed influenza and clinically diagnosed cases. We will consider your point when we reanalyze our data. (As a result of the discussion on whether or not influenza should be included among the enteric disease group, the authors decided to omit it from their study and to reanalyze the data accordingly. Please note that the enteric disease data appearing in the symposium proceedings do not include influenza. —Ed.)

DR. RYLANDER: We were impressed with the first study which appeared in *Science* with regard to the higher rate of influenza in effluent-irrigating kibbutzim. In several of our studies, we have seen that it is very difficult to distinguish between clinical findings in this type of disease. We felt that some of these symptoms were supported by your findings, but this did not correlate well with a number of other studies. My question is, did you consider this?

MR. FATTAL: In reference to this question, I can only repeat what I said to Dr. Cliver, and we will consider this point when reanalyzing the data.

DR. GERBA: Is the effluent generated by the kibbutz itself or does it come from outside sources? In other words, do they take sewage from another community and use it?

MR. FATTAL: As far as effluent-irrigating kibbutzim are concerned, some use their own effluent as well as outside effluents (from neighboring cities and communities) while others depend solely on their own sources.

DR. GERBA: It would be very important to differentiate the sewage.

MR. FATTAL: Absolutely. We are aware of this, thank you, and we will analyze the data accordingly.

DR. LUE-HING: I have difficulty with the interpretation others have made of the *Science* paper argument. Do you agree with its conclusions or don't you?

MR. FATTAL: As I have already stated, we have only presented data on one-third of the kibbutzim in this study. Thus, our results are at this point incomplete. Therefore, I do not want to comfirm or rebut the results of the first retrospective study. I suggest that you wait until all the data have been analyzed in depth with a detailed breakdown of each disease, age group, etc.

Health Effects of Occupational Exposure to Wastewater

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ABSTRACT

The primary objective of this research was to determine the health effects, if any, associated with occupational exposure to biological agents present in municipal wastewater. An additional objective was to determine the sensitivity of our methodology for detecting potential health impacts of other wastewater exposures such as recreational contact with surface-water receiving wastewater effluents.

The procedure was a prospective seroepidemiologic study applied to municipal wastewater workers and controls in three metropolitan areas: Cincinnati, Ohio; Chicago, Illinois; and Memphis, Tennessee. The study group consisted of more than 100 workers, who were recruited at the time they began work at activated sludge plants, and who remained in the study for a minimum of 12 months. In addition, in Cincinnati, two other wastewater-exposed groups were included: approximately 50 sewer maintenance workers and 50 primary wastewater treatment plant workers. The latter group was recruited into the study just before the start-up of plant improvements that included activated sludge facilities. The purpose of including this group was to differentiate between exposure to wastewater through aerosols and exposure to wastewater through primary wastewater treatment operations.

Exposure categories were developed for all workers in both the aerosol and wastewater groups. These categories were based on job observations by field personnel, on the results of aerosol sampling and analyses for bacteria, and on concurrent wastewater sampling and analyses for bacteria and viruses.

Our study failed to demonstrate an increased risk of infection in wastewater workers. There was no consistent evidence of increased parasitic, bacterial, or viral infections as indicated by stool examinations, cultures, or antibody surveys. Liver function tests and immunoglobulin determinations also failed to show clinically significant or consistent abnormalities in the study groups. We did observe an increased level of minor gastrointestinal illness in the inexperienced sewage-exposed workers as compared to the experienced workers and controls. These illnesses occurred most often in the second quarter of the year and did not correspond to enteroviral infections. Continuing studies will attempt to identify the cause of these illnesses.

OBJECTIVES AND STUDY DESIGN*

Exposure to wastewater has long been regarded as a potential health risk because of the wide variety of biological and chemical contituents commonly present in wastewater. Few studies are available, however, which document actual health risks of exposure to wastewater collection and treatment systems. During the years 1975 to 1979, the University of Cincinnati Medical Center conducted a comprehensive study of wastewater treatment industry workers. This U.S. EPA-supported study was a prospective seroepidemiologic investigation of wastewater workers in three cities. The focus of the study was on possible health hazards due to the viral and bacterial content of the wastewater. Physical and chemical hazards were not specifically included in the design of this study. However, wastewater industry workers are known to experience very high accident rates (1). Exposure to toxic chemicals is documented in two other papers presented at this symposium (2,3).

When the study was initiated in 1975, there were two primary objectives:

- to assess the health risk of occupational exposure to wastewater
- to determine the sensitivity of the serologic-epidemiologic method to detect effects of wastewater exposure.

In 1976, there was an increased interest in whether aerosols generated at wastewater treatment plants were a source of disease to surrounding neighborhoods. In order to gain some information regarding potential effects of aerosol exposure, our study was expanded in July 1976 by the addition of a third objective:

- to assess the health risk of occupational exposure to viable wastewater treatment plant aerosols.

At about the same time, the U.S. EPA initiated several other studies directed towards assessing the potential health impact of wastewater treatment on neighborhoods adjacent to treatment plants (4,5,6,7). The study method (Figure 1) involved collection of blood specimens and throat and rectal swabs every three months (Figure 2) for laboratory analyses, annual health examinations, environmental monitoring (Figure 3), and collection of illness information. The central feature of the laboratory studies was a battery of tests used to determine the levels of viral

1. Sero-survey (Viral and bacterial)
2. Evaluation of immune status
3. Isolation and identification of pathogens
4. Clinical illness monitoring
5. Yearly health examinations
6. Environmental monitoring

Figure 1. Method of Serologic—Epidemiologic Study

*Presented by C. Scott Clark

and bacterial antibodies and immunoglobulins in serum specimens. The testing was designed to detect changes that may occur after a person is exposed to wastewater in an occupational setting.

The specific objectives of the study were as follows:

- to determine whether wastewater workers develop specific bacterial, viral, and parasitic infections due to occupational exposure to sewage
- to determine the immunologic response among workers presumed to be exposed to a high level of antigenic stimulation, i.e., wastewaters
- to determine whether wastewater workers serve as a reservoir of certain infections and, if so, whether members of the workers' families are affected
- to determine the effect of exposure to aerosols generated by the activated sludge treatment process
- to determine the concentration of bacterial aerosols at wastewater treatment plants.

Volunteers in the study were asked to participate for a minimum of 12 months, if possible.

Blood (45 ml)
Throat swabs[a]
Rectal swabs[a]
Urine[b]
Stool[b]

[a] Also collected at times of illness

[b] During first 15 months of study in Cincinnati only

Figure 2. Biological Specimens Collected Quarterly from Study Participants

Sample type	Locations	Determinations
Wastewater:		
24-hour composite	Primary and secondary effluent	Enteroviruses
Grab	Primary and secondary effluent	Standard plate count, total and fecal coliforms, fecal streptococcus
Air	Various locations	Standard plate count, total and fecal coliforms, fecal streptococcus

Figure 3. Environmental Monitoring

Related Studies

Recent literature searches have revealed little evidence of occupational health problems associated with wastewater pathogens (8,9). The few situations in which adverse health effects have been found involved sewage farming with untreated wastes or other contact with essentially raw sewage (10,11,12). A comprehensive retrospective study of Berlin sewer workers by Anders failed to reveal any health problems associated with sewage pathogens (13).

In Sweden, Rylander and his associates describe what they call a "sewage workers syndrome," found in workers in a sludge-drying operation producing dust mostly in the respirable size range (14). Symptoms of this syndrome include eye discharges and fever which usually develop several hours after the end of the work day. Laboratory testing revealed elevated levels of the immunoglobulin IgA and elevated levels of white blood cells. Their investigation has been extended to other wastewater treatment plants; results from these studies appear elsewhere in the proceedings of this symposium (15). Layton has reported that new employees in the wastewater industry sometimes experience dysentery during the first year of employment but appear to have no unusual ill effects thereafter (16). A preliminary report of a study of wastewater treatment workers in Copenhagen, Denmark, suggests that the workers experience elevated immunoglobulin levels and elevated levels of antibodies against Weil's disease (17). Dean (18) reports on other aspects of the Copenhagen study elsewhere in this symposium. Earlier studies in Germany (12) and Ceylon (11) also report elevated levels of antibodies against Weil's disease. Weil's disease can be transmitted by the urine of infected rats and may resemble influenza in its earlier stage.

Populations Selected

The populations selected for the initial portion of the study were Cincinnati sewer maintenance workers; Cincinnati highway maintenance workers served as the comparison group. The protocol required recruiting a minimum of 30 inexperienced sewer maintenance workers just as they were starting work, 30 experienced sewer maintenance workers, and comparable groups of highway maintenance workers. Sewer maintenance workers were thought to have more intimate contact with sewage in Cincinnati then sewage treatment plant workers. Soon after the study began in 1975, a moratorium on municipal employee hiring in Cincinnati made recruitment of highway maintenance workers who just starting work impossible, and it severely impeded recruitment of inexperienced sewer maintenance workers, although some hiring continued for this work group. When the study was expanded in mid[redacted] determine the potential occupational health effects of exposure to activated sludge plant aerosols, the research design was expanded to include two additional exposed population groups. These groups were: 1) 50 men employed at the Cincinnati Mill Creek Sewage Treatment Plant, which was in the process of being expanded from primary wastewater treatment to include the activated sludge process; and 2) 100 men newly employed at activated sludge treatment plants. The latter group was recruited from Cincinnati, Ohio; Chicago, Illinois; and Memphis, Tennessee. As additional control groups, water treatment plant workers were selected in Chicago; in Memphis, workers at the Memphis Light, Gas and Water Division were selected. Chicago was chosen because the large size and long history of the Metropolitan Sanitary District of Greater Chicago provided a relatively large number of inexperienced workers as a result of routine work-force attrition. Memphis was chosen because its second treatment plant was almost completed and the employees expected to be hired would be primarily those without any prior occupational exposure to wastewater.

Initial recruitment began in April 1975 when the first inexperienced sewer maintenance workers in Cincinnati joined the study. Chicago workers joined the study in July 1976 and Memphis workers in 1977, since that was the time when initial hiring began at the newly-completed Memphis North Wastewater Treatment Plant. A listing of the dates of initial recruitment of all study groups appears in Figure 4. Volunteer recruitment was completed by the first quarter of 1978, and the last specimens were collected during the final months of that year. The total number of volunteers recruited in the various work groups is shown in Table 1. Over 500 workers participated in the study, but not all workers remained in the study for the entire period. Family members of study participants were invited to participate in a family study designed to determine if wastewater workers served as a source of infection for their families. Single blood specimens were collected from individuals participating in the study. A summary of the 128 families and number of specimens collected is presented in Table 2.

Table 1. Number of Volunteers Recruited Into Study

Group	Cincinnati	Chicago	Memphis
Inexperienced Activated Sludge	44	56	50
Experienced Activated Sludge	54	40	17
Inexperienced Sewer Maintenance	13	0	0
Experienced Sewer Maintenance	65	0	0
Controls	80	50	55
	256	146	122

Table 2. Family Study[a]

		Number of Families		
Worker group	Cincinnati	Chicago	Memphis	Total
Inexperienced Sewage Exposed	13	13	16	42
Experienced Sewage Treatment	24[b]	19	2	45
Control	12	11	18	41
Total No. Families	49	43	36	128

[a] Total numbers of specimens collected from household members in Cincinnati, Chicago, and Memphis were 170, 130, and 129, respectively

[b] Includes 9 families of sewer maintenance employees with total of 31 specimens

April 1975	Inexperienced sewer maintenance	— Cincinnati
July 1975	Inexperienced sewage treatment	— Cincinnati
July 1975	Sewer and highway maintenance	— Cincinnati
July 1976	Experienced sewage treatment	— Cincinnati and Chicago
July 1976	Inexperienced sewage treatment	— Chicago
October 1976	Water treatment	— Chicago
July 1977	Sewage treatment	— Memphis
October 1977	Light, gas and water	— Memphis

Figure 4. Date of Initiation of Recruitment

ENVIRONMENTAL MONITORING, STATISTICAL PROCEDURES, AND POPULATION CHARACTERISTICS*

Environmental Monitoring

The environmental monitoring consisted of aerosol sampling at various worksites for respirable concentrations of bacteria, and wastewater sampling for viruses and bacteria (Figure 3). The virus assay of wastewater in all three cities was performed by the Metropolitan Sanitary District of Greater Chicago. Six-liter, twenty-four-hour composite samples for virus assay were concentrated using an $Al(OH)_3$-continuous flow centrifuge technique (19). Virus content was estimated by using a plaque assay procedure that used three cell cultures: 1) BGM (Buffalo green monkey kidney cells; 2) WI-38 (human diploid cell strain); and 3) PMK (primary monkey kidney cells). The aerosol samples were collected using six-stage, viable-particle Andersen samplers, and were analyzed for fecal streptococci (FS), fecal coliform (FC), total coliform (TC), and standard plate count (SPC). The samplers were used to collect the aerosols from about 0.4 m^3 of air (20). Each sampler contained six molded Andersen glass petri dishes containing 27 ml of plate count agar. A replicate plate method was used for determining the total coliform (TC), fecal coliform (FC), and fecal streptococcus (FS) counts on the petri dishes from the Andersen samplers. Bacterial analyses of wastewater and aerosols were performed in Chicago by the Metropolitan Sanitary District of Greater Chicago; in Memphis by the Memphis State University; and in Cincinnati by our staff. Bacterial analyses were performed according to "Standard Methods" (21). Results of the air sampling were used to determine relative levels of airborne bacteria at various worksites. Based on this information, each worker was categorized according to his exposure level relative to other workers at the same treatment plant. The exposure categories were "above average" and "average or below average". Wastewater and sludge exposure levels were determined by a combination of survey questionnaire and job observation by field personnel. Again, exposure categories were either "above average" or "average or below average".

After each group of workers was subdivided into exposure categories, clinical and laboratory findings were examined to see whether there was any variation within a worker group as a result of exposure level.

Tables 3, 4, and 5 summarize airborne bacterial levels for Cincinnati, Chicago, and Memphis, respectively. Results are based on plate counts for stages 3 through 6 of the Andersen samplers.

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*Presented by Gretchen L. Van Meer

Table 3. Environmental Monitoring - Aerosol Respirable Bacterial Count/m³ - Cincinnati

	No samples	Standard plate count	Total coliform	Fecal coliform	Fecal streptococci
Mill Creek Sewage Treatment Plant					
Inside - no wastewater	5	43	0	0	0
Inside - wastewater operations	17[a]	761	20	4	10
Aeration basins	17[b]	812	8	1	2
Settling tanks	5	280	7	0	1
Other outdoor	22	320	6	2	3
Sewer maintenance					
Inside	5	374	0	0	0
Outside	1	16	0	0	0
Highway maintenance					
Inside	11	93	0	0	0
Outside	9	9	0	0	0
Street cleaning	2	1,121	15	1	15

[a] One sample too numerous to count

[b] Two samples too numerous to count

Table 4. Environmental Monitoring - Aerosol Respirable Bacterial Count/m³ - Chicago

	No samples	Standard plate count	Total coliform	Fecal coliform	Fecal streptococci
West Southwest Sewage Treatment Plant					
Inside	7	973	18	6	10
Aeration basins	11	253	13	6	2
Aerated grit chamber	1	315	33	0	12
Other outdoor	10	196	23	6	9
Calumet Sewage Treatment Plant					
Aeration basins	11	292	4	3	2
Aerated grit chamber	2	368	30	16	30
Other outdoor	10	212	0	0	0
Water treatment plant	8	38	8	2	2

Table 5. Environmental Monitoring - Aerosol Respirable Bacterial Count/m³ - Memphis

	No samples	Standard plate count	Total coliform	Fecal coliform	Fecal streptococci
North Sewage Treatment Plant					
Inside - no wastewater	7	73	7	5	8
Aeration basins	25	736	43	12	55
Aerated grit chamber	10	522	42	29	30
Other outdoor	12	150	27	3	4
Maxson Sewage Treatment Plant					
Aeration basins	11	583	68	45	66
Aerated grit chamber	3	326	177	91	343
Other outdoor	6	184	13	4	30

Statistical Procedures

Statistical procedures used primarily included analyses of covariance, where the data are continuous, and the chi-square test, where the data are discrete.

Examples of analyses of covariance are given in Tables 6 and 7 for liver function tests and immunoglobulins, respectively, for Chicago workers in 1978. The data were examined for distribution, and when it was not normal, a transform was used. For all the data in this study which were not normally distributed, a log transform was sufficient. This was done for three of the five liver function tests and for all the immunoglobulins tested.

Table 6. Yearly Health Exam - Liver Function Tests - Chicago 1979

	Inexperienced	Mean Values Experienced	Controls	p[b]
SGOT[a]	29.1	27.1	24.0	022
SGPT[a]	13.9	13.7	12.1	221
Albumin	4.6	4.4	4.4	882
Alkaline phosphatase[a]	73.7	71.5	64.7	.090
Total bilirubin	.58	.59	.69	.070

[a] Geometric mean

[b] By analysis of covariance, with age and race covariates

Table 7. Immunoglobulin Levels (mg/d1) Chicago

		Geometric Means			Significance	
		Experienced	Control	Significance[a]	Age	Race
1/78	IgA	189 (50)[b]	191 (31)	252	030	.001
	IgG	1,200	1,200	546	.721	<.001
	IgM	83	81	904	.149	489
10/78	IgA	172 (44)	179 (30)	546	.021	.024
	IgG	1,119	1,153	.781	.727	146
	IgM	74	72	.736	873	232

[a] By analysis of covariance

[b] Number of persons

Covariates used were age and race, and significance levels provided in the tables reflect this adjustment.

The virus serology procedure consisted of serial dilutions, and the data consisted of the highest dilution level for each worker for which antibody was found. An example of a contingency table of this kind of data is Table 8, which shows results for Chicago sera analyzed for antibody to Polio 3 in January, 1978. The chi-square test was used to ascertain whether there was a significant difference in the distribution of titer levels. If a difference existed, it was not always obvious which group had the higher average titer level. Occasionally, the distributional difference might have been a result of higher and lower titers in one group and medium titers in the other. In order to facilitate interpretation of the results, the geometric mean titer level is given for each group. To calculate the geometric mean for values below detection level, which was less than 2 in this test, half the detection level was arbitrarily used, that is, 1, in this case.

In addition to the question of differences in distribution of titers between groups, the question arises as to whether there were differences between groups in titer level changes from one time period to another. An example of a contingency table of this type of data is given in the second part of Table 8. Of particular interest are increases of fourfold or greater (two or more titer levels) because of their potential medical significance. However, the chi-square test, which was used for the entire contingency table, includes all changes.

Table 8. Virus Serology—Chicago—Antibodies to Polio 3

	Titer Levels										
	<2	2	4	8	16	32	64	≥128	N	Geometric mean	p[*]
1/78 Experienced	2	2	3	5	9	6	8	9	44	23.4	
1/78 Control	2	3	2	3	4	4	3	3	24	13.88	898

Titer level changes January-October 1978

	Increases			No change	Decreases				
	3	2	1	0	1	2	3	N	p[*]
Experienced	0	1	6	27	6	3	0	43	
Control	1	2	6	9	4	1	0	23	283

[*] By chi-square

Similar procedures were used to evaluate the differences between high and low-to-medium exposed workers for both aerosols and wastewater, and for differences that were a result of age or race, as indicated in Table 9. The data are for the same group of exposed workers shown in Table 8. In Table 9 this group is divided on the basis of aerosol exposure in the first part, wastewater in the second part, age in the third part, and race in the fourth part. Again, the geometric mean titer levels are included to facilitate interpretation of the results.

In the examples given in Tables 6 through 9 there were no significant differences ($p \leq .01$). However, these same procedures were initially used for 31 viruses in six worker groups for three time periods in two cities. With this quantity of comparisons, by the laws of probability, results will be significant 1% of the time, and it is essential to guard against Type II errors (false positives). It is possible in some situations to adjust the significance value, for example, by multiplying by the number of tests done. However, in a study of this size there is also the risk of suppressing genuine differences. The best method of evaluation in a case like this is to inspect all differences that appear to be significant in order to see whether there is any apparent trend or whether these outcomes are random and within the limits of the expected number of significant differences in a study of this size. Summaries of significant differences for virus serology are given in the results section of this paper.

Table 9. Virus Serology—Chicago - January 1978 Antibodies to Polio 3 - Exposed Workers

	Titer Levels										
	<2	2	4	8	16	32	64	≥128	N	Geometric mean	p^a
Aerosol exposure											
High	2	0	1	2	3	2	3	7	20	28.8	
Low-Med	0	2	2	3	7	4	4	2	24	18.5	.228
Wastewater Exposure											
High	1	1	1	2	5	2	5	9	21	24.6	
Low-Med	1	1	2	3	5	4	2	5	23	21.0	936
Age											
≤40	1	1	1	4	7	3	5	3	25	20.5	
>40	1	1	2	1	3	3	2	6	19	25.7	624
Race											
Black	0	1	0	2	1	1	2	2	9	25.4	
White	2	1	3	3	9	5	5	7	35	22.0	525

[a] By chi-square

Population Characteristics

In a study consisting of volunteer subjects, the question arises as to whether those who participated differ appreciably from those who qualified and were invited, but chose not to participate. While the information available on the nonparticipants is more limited than on the volunteers, data for a number of parameters were collected, namely, age, race, salary, job class, and, in some cases, years of school (Figure 5). For each parameter in each worker group, the participants were compared with the nonparticipants. Data were put in contingency tables; 5-year groupings were established for age, and $2,000-$2,500 increments were established for salary. Comparisons were performed using the chi-square test. Table 10 shows the number of workers used in each group, the mean values and range for age, the mean values for years of school, and the median ranges for salary, along with the significance level for each comparison. Job classification comparisons and the significance for

Type	Participants	Nonparticipants
Age	X	X
Race	X	X
Salary	X	X
Years experience	X	X
Household composition	X	
Education	X	
Household income	X	

Figure 5. Socioeconomic Data Collected

each comparison are given in Table 11 for all 3 cities. The chi-square procedure was used. Additional data are still being collected from nonparticipants in the control groups in Chicago and Memphis. The differences that exist between participants and nonparticipants are not expected to influence study results.

More information is available for participants in the study; this information can be used to ascertain comparability of the exposed and control groups with regard to socioeconomic status (SES). Available data

Table 10. SES Data Comparing Study Participants With Nonparticipants

	Age (years as of 1978)								
	Cincinnati			Chicago			Memphis		
	N	Mean	Range	N	Mean	Range	N	Mean	Range
Inexperienced sewage exposed									
Participant	52	30.8	19-64	55	38.8	19-61	50	27.9	19-57
Nonparticipant	24	32.8	21-64	68	39.8	19-62	62	34.2	19-63
p[a]		.507			920			040	
Control									
Participant	74	43.1	22-67	39	28.2	22-76	56	40.9	19-67
Nonparticipant	86	38.7	21-64	96	28.2	22-69	61	40.1	20-70
p[a]		.197			750			850	
Experienced sewer maintenance									
Participant	65	40.9	24-66						
Nonparticipant	13	41.2	27-63						
p[a]		.464							
Experienced sewage treatment									
Participant	56	37.8	20-63						
Nonparticipant	11	42.8	24-62						
p[a]		.154							

	Race					
	Cincinnati		Chicago		Memphis	
	Nonwhite	White	Nonwhite	White	Nonwhite	White
Inexperienced sewage exposed						
Participant	19	27	14	40	10	40
Nonparticipant	10	14	12	54	12	41
p[a]	.821		.310		.750	
Control						
Participant	52	21			22	35
Nonparticipant	59	30			33	49
p[a]	.500				.840	
Experienced sewer maintenance						
Participant	54	11				
Nonparticipant	4	8				
p[a]	.001					
Experienced sewage treatment						
Participant	24	34				
Nonparticipant	3	10				
p[a]	.273					

[a] By chi-square

[b] By chi-square with Yates' correction

Table 10. SES Data Comparing Study Participants With Nonparticipants (Continued)

	Years school			
	Cincinnati		Chicago	
	N	Mean	N	Mean
Inexperienced sewage-exposed				
Participant	51	12.4	51	12.3
Nonparticipant	24	11.8	59	12.4
p[b]	.003		930	
Control				
Participant	64	11.6		
Nonparticipant	86	11.0		
p[a]	.013			
Experienced sewer maintenance				
Participant	64	11.2		
Nonparticipant	12	11.3		
p[b]	.791			
Experienced sewage treatment				
Participant	60	12.0		
Nonparticipant	12	13.8		
p[b]	.047			

	Salary—median range (× $1000)					
	Cincinnati		Chicago		Memphis	
	N	Median	N	Median	N	Median
Inexperienced sewage exposed						
Participant	45	9.6-12.1	52	14.1-16	39	9.6-12.1
Nonparticipant	24	9.6-12.1	68	16.1-18	65	9.6-12.1
p[a]	372		.025		730	
Control						
Participant	72	12.1-14			48	12.1-14
Nonparticipant	92	9.6-12.1			84	12.1-14
p[a]	.002				140	
Experienced sewer maintenance						
Participant	64	9.6-12.1				
Nonparticipant	12	12.1-14				
p[b]	.067					
Experienced sewage treatment						
Participant	57	9.6-12.1				
Nonparticipant	11	7-9.6				
p[b]	.040					

[a] By chi-square

[b] By chi-square with Yates' correction

also include household size and household income, more meaningful measures of SES than salary. Comparisons for these parameters are given in Table 12 for each worker group in each city. There are significant differences for age ($p \leq .01$) and for race ($p \leq .05$), which is why these covariates are used in the analyses of covariance and the virus serology data are examined for differences based on age or race. When virus serology data were examined for age and race effect, few differences were found. These differences are not thought to influence the results of the study. Household sizes are similar in Cincinnati and

Table 11. Comparison of Participating with Nonparticipating Job Class

	Participating	Nonparticipating	Participating	Nonparticipating	Participating	Nonparticipating	
	Operator		Laborer		Other		p[a]
Cincinnati inexperienced sewage-exposed	15	8	19	15	11	2	.084
Cincinnati experienced sewage treatment	31	6	12	3	17	6	603
Cincinnati experienced sewer maintenance	15	5	38	5	11	2	.413
Cincinnati controls	28	28	19	54	22	10	.001
	Maintenance Laborer A		Maintenance Laborer B		Security Guard		
Chicago inexperienced sewage treatment	18	40	25	20	8	8	.040
	Operator/ Supervisor		Tradesman/ Laboratory		Laborer		
Memphis inexperienced sewage treatment	24	34	8	29	12	10	.033
	Lineman		Crew Leader/ Foreman		Other		
Memphis controls	18	23	11	12	25	30	450

[a] By chi-square

Chicago, but in Memphis, although the means are similar, the distribution of family sizes is different. The exposed groups are somewhat better educated than the controls, though household income is less. This however, may be a reflection of the younger age (which is to be expected in a group of inexperienced workers) of the individuals in this group.

CLINICAL AND LABORATORY FINDINGS*

My personal bias at the beginning of this study was that we would easily find evidence of increased infections in workers exposed to sewage, although we might not find an increase in clinical illness. The preliminary findings of the study, which are reported here, do not support that opinion. Dr. Van Meer has discussed in detail some of the problems encountered when evaluating the results of an epidemiologic survey of this type, in contrast to a study which focuses on a more limited question. Therefore, in the presentation of the results, I will indicate the number of comparisons made in various aspects of the study, and the trends of the differences observed. In addition, I will attempt to indicate the clinical significance. The correlation of the environmental sampling data with clinical and laboratory findings has not been analyzed and will not be presented. The results will be discussed in four sections: 1) clinical illness; 2) laboratory tests; 3) evidence of infection; and 4) the family study.

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*Presented by Calvin C. Linnemann

Table 12. SES Data for Workers in Final Virus Serology[a]

	Age (years, as of 1978)								
	Cincinnati			Chicago			Memphis		
	N	Mean	Range	N	Mean	Range	N	Mean	Range
Inexperienced sewage exposed	33	33.6	20-64	49	38.9	19-60	43	27.4	19-57
Control	46	47.0	22-66	25	50.9	28-76	50	37.7	19-67
Experienced sewer maintenance	40	37.2	24-60						
Experienced sewage treatment	41	38.0	22-63						
		$p < .001$			$p = .009$			$p < .001$	

	Race					
	Cincinnati		Chicago		Memphis	
	Nonwhite	White	Nonwhite	White	Nonwhite	White
Inexperienced sewage exposed	13	16	11	38	8	35
Control	28	18	12	12	20	31
Experienced sewer maintenance	36	4				
Experienced sewage treatment	19	22				
	$p < .001$		$p = .019$		$p = .033$	

	Household size					
	Cincinnati		Chicago		Memphis	
	N	Mean	N	Mean	N	Mean
Inexperienced sewage exposed	33	3.6	49	3.6	41	3.6
Control	41	3.8	25	3.2	49	3.8
Experienced sewer maintenance	40	3.4				
Experienced sewage treatment	45	3.7				
	$p = .790$		$p = .791$		$p = .025$	

[a] All procedures done using chi-square test on contingency tables of raw data; intracity comparisons only; N = number of workers or worker's families represented.

Table 12. SES Data for Workers in Final Virus Serology[a] (Continued)

	Years school					
	Cincinnati		Chicago		Memphis	
	N	Mean	N	Mean	N	Mean
Inexperienced sewage exposed	32	12.5	48	12.4	39	13.2
Control	42	11.5	23	10.8	47	11.0
Experienced sewer maintenance	40	11.1				
Experienced sewage treatment	41	12.1				
	p< .001		p = .041		p = .006	

	Household income - median range (× $1000)					
	Cincinnati		Chicago		Memphis	
Inexperienced sewage exposed	29	9.6-12	48	14.1-16	39	9.6-12
Control	45	14.1-16	24	25	45	14.1-16
Experienced sewer maintenance	40	12.1-14				
Experienced sewage treatment	41	14.1-16				
	p = .100		p <.001		p = .002	

[a] All procedures done using chi-square test on contingency tables of raw data; intracity comparisons only; N = number of workers or worker's families represented

Clinical Illness

The illnesses which occurred in the study populations were categorized as respiratory, gastrointestinal, combined respiratory and gastrointestinal, and other. This reflects our primary concern with respiratory and gastrointestinal illnesses. Figure 6 and Table 13 show the occurrence of clinical illnesses in the combined study groups. The number of illnesses is expressed per 100 worker-months of exposure. This was necessary because of variations in duration of the workers' participation in the study. The illness rates are presented quarterly in order to allow interpretation of seasonal patterns. Total illnesses, which peaked in the first or winter quarter, reflected the increase in respiratory illnesses. There were no major variations in the other illness categories. Upon examination of clinical illnesses by worker groups (Table 14) we find that respiratory illnesses are the most common illnesses in all groups; the highest total illness rates occur among the inexperienced and experienced treatment workers. The only statistically significant difference in illness rates between worker groups and/or controls was the difference in gastrointestinal illness among inexperienced workers and in other groups. This is illustrated in Figure 7, and, as can be seen, the difference is greatest in the second quarter of the year. These were minor gastrointestinal illnesses and did not appear to correspond with enteroviral infections.

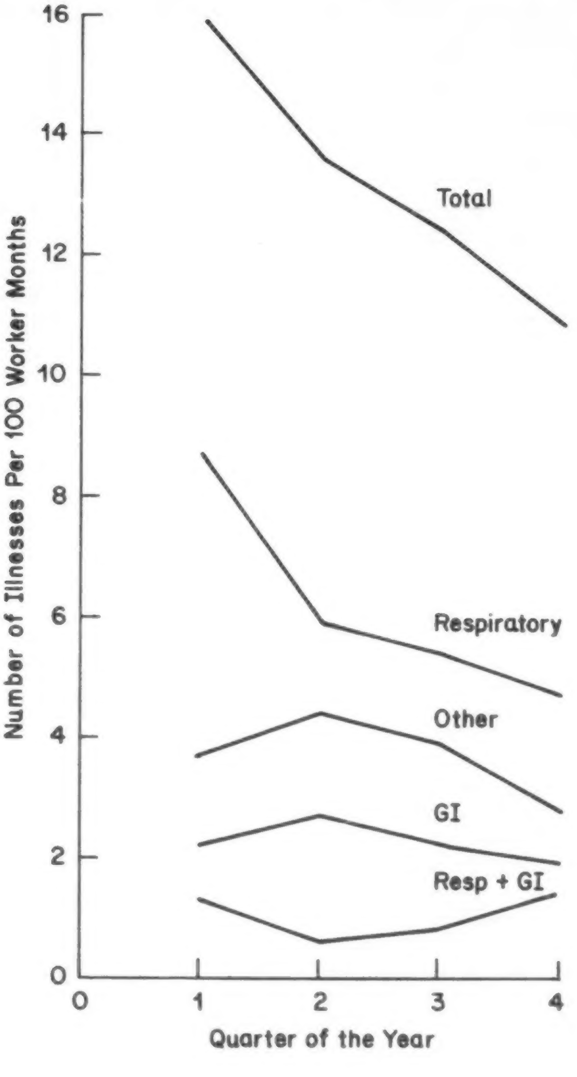

Figure 6. Clinical Illnesses in All Study Participants, Including Wastewater Workers and Controls

Table 13. Clinical Illness in All Study Participants, Including Wastewater Workers and Controls

	Type of illness[a]				
Quarter of Year	Respiratory	Gastrointestinal	Respiratory and Gastrointestinal	Other	Total
January-March	8.7	2.2	1.3	3.7	15.9
April-June	5.9	2.7	0.6	4.4	13.6
July-September	5.4	2.2	0.8	3.9	12.4
October-December	4.9	1.6	1.4	2.8	10.8

[a] Per 100 worker-months of exposure

Table 14. Clinical Illness in Wastewater Worker Groups

	Type of illness[a]				
Worker	Respiratory	Gastrointestinal	Respiratory and Gastrointestinal	Other	Total
Inexperienced	6.5	3.6	1.7	3.8	15.6
Experienced					
Maintenance	5.5	1.3	0.5	4.0	11.3
Treatment	8.0	2.4	0.9	3.6	14.9
Control	4.9	1.5	1.0	3.3	10.7

[a] Per 100 worker-months of exposure

Laboratory Tests

As indicated by Dr. Clark, a variety of laboratory tests were performed on each worker, including complete blood counts, urinalysis, blood chemistries, and tests of immunoglobulin levels. We were particularly interested in liver function tests because of the possibility of hepatitis. Table 15 shows the geometric mean values for the SGOT and SGPT for each worker group in each city by study year. It is apparent that the means for all groups are within normal limits. The mean SGOT is slightly higher for the experienced sewer maintenance workers in Cincinnati, but the SGPT in the experienced sewer maintenance worker group is lower than in the unexperienced worker group. The SGPT is an enzyme which is more specific for liver than is the SGOT. None of these differences between the groups was significant at $p \leq .01$ level. The results of the liver tests provided no evidence of an increase in hepatitis in workers exposed to wastewater.

Immunoglobulin levels were determined because other studies of wastewater workers have reported higher levels of immunoglobulins, although the reported differences are not statistically significant. Theoretically, continuing antigenic stimulation from wastewater could produce elevated immunoglobulin levels. In the present study, immunoglobulin levels were measured in inexperienced workers at the initial time of employment and compared to the levels three months later. As shown in Table 16, there were no significant differences. Immunoglobulin levels of study groups were also compared at intervals throughout the study period. The values for one of the three cities are shown in Table 17. This is typical of all cities; there were no consistent differences between study groups. Year to year variations could not be compared,

Table 15. Results of Liver Function Tests in Each Study Group, by City

	Year	Test	Geometric mean values by worker group: Inexperienced sewer-exposed	Experienced sewer maintenance	Experienced sewer treatment	Control
Cincinnati	1976	SGOT	25.5	32.5	23.6	25.5
	1977	SGOT	27.1	35.2	26.6	26.6
		SGPT	27.9	18.2	17.5	20.5
	1978	SGOT	23.3	30.3	23.8	27.7
		SGPT	21.1	20.3	19.5	20.3
Chicago	1977	SGOT	28.2		23.8	26.0
	1978	SGOT	29.1		27.1	24.0
		SGPT	13.9		13.7	12.1
Memphis	1977	SGOT	27.1			24.3
		SGPT	15.0			12.1
	1978	SGOT	19.1			17.5
		SGPT	18.0			13.7

since tests were not done simultaneously. However, the first and last sera from one group of inexperienced workers were measured simultaneously and there was no change in immunoglobulin levels. Therefore, the study failed to demonstrate increased or changed immunoglobulin levels in wastewater workers.

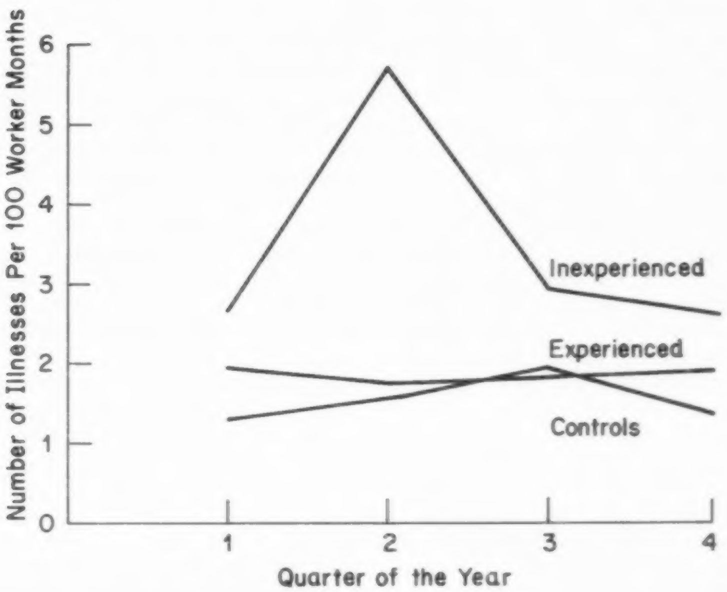

Figure 7. Gastrointestinal Illnesses in Inexperienced and Experienced Wastewater Workers and Controls

EVIDENCE OF INFECTION

Parasitic

To evaluate the frequency of parasitic infection in sewer maintenance workers, a prevalence survey was conducted in the first year of the study. Stool specimens were collected from 136 men, including 69 controls, 19 new employees who had not been exposed to sewage, and 48 experienced maintenance workers (Table 18). Parasites were found in 11.6% of the controls and in 10.5% of the new employees but in none of the sewage-exposed workers. An additional 196 stool examinations were performed over the following year, but the identification of parasites was similar in the sewage-exposed and nonexposed workers. There was no evidence of increased parasitic infection in the wastewater workers.

Table 16. Immunoglobulin Levels in Inexperienced Wastewater Workers[a]

Type	Cincinnati		Chicago		Memphis	
	First serum	Second serum	First serum	Second serum	First serum	Second serum
IgG	1,954	1,804	2,461	2,065	1,113	900
IgM	83	82	94	96	83	110
IgA	176	171	196	192	183	193

[a] Mean values, mg/d1

Table 17. Immunoglobulin Levels by Wastewater Worker Group in Cincinnati

Year of study	Worker group	Immunoglobulin level[a]		
		IgG	IgM	IgA
1975	Experienced sewer maintenance	2,176	126	327
	Control	2,857	95	281
1976	Experienced sewer maintenance	2,183	689	268
	Experienced sewage treatment	2,486	78	183
	Control	2,537	69	233
1978	Experienced sewer maintenance	1,451	84	179
	Experienced sewage treatment	1,188	74	167
	Inexperienced sewage-exposed	1,636	84	156
	Control	1,451	73	226

[a] Mean values, mg/d1

Bacterial

Rectal swabs were obtained from workers and controls, and cultured for *Salmonella* and *Shigella*. The results of these cultures are summarized in Table 19. *Salmonella* were isolated from six of 206 workers exposed to sewage, and *Shigella* were isolated from one of 171 controls. This is not a significant difference.

Antibody titers were measured for *Salmonella*, *Leptospira*, and *Legionella pneumophila* serotype 1. There were no differences in *Salmonella* antibody in limited studies in the first 3 years of the study. In the final year, sera from all men were tested by a microagglutination technique for antibodies to *Salmonella* groups A through E. Forty-five comparisons were made between groups of workers and controls. This included comparisons of antibody levels in sera collected from each man in January and October and of seroconversion between the two sera. These three comparisons were repeated for the five *Salmonella* groups in each of the three cities in the study. In 45 comparisons there were no differences between groups which were significant at the $p \leq .01$ level. There were only four differences which were significant at the $p \leq .05$ level.

Table 18. Prevalence of Parasites in Stools by Worker Group in Cincinnati

Worker Group	No. of Workers	Positive Stool (%)	Parasite (No. of workers)
Nonexposed			
Controls	69	8 (11.6)	*Giardia* (1) *E. nana* (5) *Isospora* (2)
New employees	19	2 (10.5)	*Giardia* (1) *Strongyloides* (1)
Exposed			
Sewer maintenance	48	0	—
Total	136	10 (7.4)	

Table 19. *Salmonella* and *Shigella* Isolations from Rectal Swabs

Worker Group	No. of Workers	Positive Cultures	%
Exposed to sewage	206	6	2.9
Nonexposed	171	1	0.6

Two prevalence surveys for antibody to *Leptospira* were conducted in 1977 and 1978 (Table 20). Antibody was measured by Dr. C. Sulzer in the Leptospirosis Reference Laboratory of the Center for Disease Control with a microscopic agglutination technique that used over 20 serovars. In 1977, a survey of 124 men indicated that the prevalence of antibody was greater in workers who were not exposed to sewage (Table 20). In 1978, an expanded survey including 357 men showed a higher prevalence of antibody in the workers who were exposed to sewage. The differences were not statistically significant.

In the final year of the study, a prevalence survey for antibody to *Legionella pneumophila* was conducted by use of a fluorescent antibody technique. This test was added to the study because of increasing epidemiologic data which suggested that this was a soil organism which could be acquired from environmental sources. The results of the survey are shown in Table 21. Screening at a 1:64 dilution of serum, 34.4% of the workers exposed to sewage and 35.4% of the nonexposed workers had antibody. The level of antibody was slightly higher in sewer maintenance workers compared to sewer treatment workers, but the difference is not statistically significant.

Table 20. Prevalence of Leptospiral Antibody

Worker Group	No. of Workers	No. with Antibody	%
1977			
Sewage-exposed	57	7	12.3
Nonexposed	67	19	28.4
1978			
Sewage-exposed	225	11	4.9
Nonexposed	132	1	0.8

Table 21. Prevalence of Antibody to *Legionella pneumophila*

Worker Group	Fluorescent Antibody Titer[a]		% Positive
	<64	≥64	
Sewage-exposed	179	94	34.4
Maintenance	40	29	42.0
Treatment	139	65	31.9
Nonexposed	117	64	35.4

[a] Reciprocal of the serum dilution

Viral

The possibility of an increase in viral infections among wastewater workers was tested by the use of throat cultures and rectal swabs for viruses, and by use of extensive serologic surveys. Viral cultures were performed in Rhesus monkey kidney, WI-38, Vero and HeLa cells. The numbers and types of viruses isolated are shown in Table 22. Herpes simplex virus was isolated most frequently and enteroviruses were the second most common isolate. Our major concern in this study was the occurrence of enteroviral infections because of the frequency with which enteroviruses can be recovered from wastewater. Although more enteroviruses were recovered from wastewater workers, the recovery rates were not significantly different. The results for the study participants in Cincinnati are presented in Table 23. The specific enteroviruses which were isolated from the participants are shown in Table 24 along with those enteroviruses which were recovered from wastewater samples during the study.

Table 22. Virus Isolations from Throat and Rectal Swabs

Study group	Type of Virus				
	Entero	Adeno	Rhino	Herpes	Flu A
Wastewater	15	1	4	18	3
Control	3	3	1	12	1
Total	18	4	5	30	4

Table 23. Enterovirus Isolations from Study Participants in Cincinnati

Worker group	No. of workers	Number excreting enterovirus	%
Exposed to sewage	183	6	3.3
Nonexposed	78	2	2.6

Table 24. Enteroviruses Recovered During the Study

Viruses	Wastewater monitoring	Study participants
Polio	1-3	1,3
Coxsackie	A15; B1, 3-5	A13; B2,4,5
Echo	1-4, 6,7,9,13,18,33	3,9,21,29

The serologic testing for viral antibodies was performed in two large surveys. The viruses which were included in the initial survey are shown in Table 25, and those in the final survey are shown in Table 26. Most of these are enteroviruses, antibody was measured by a microneutralization technique. The specific viruses were selected on the basis of recovery of viruses from workers and wastewater in the study or by viral diagnostic laboratories in the study areas. Several nonenteroviruses were also included, and antibody was measured by complement fixation for most of these.

Table 25. Viruses Included in Initial Virus Serology Survey

Polio	1,2,3
Coxsackie	A7,9,16,21; B1-6
Echo	1-4, 6, 8, 9, 11, 13, 14, 19, 24, 25, 30
Adenovirus	
Reovirus	
Herpes simplex	
Cytomegalovirus	

Table 26. Viruses Included in Final Virus Serology Survey

Polio	1, 2, 3
Coxsackie	A9; B1-5
Echo	3, 6, 8, 9, 11, 21
Adenovirus	
Herpes simplex	

There were many comparisons made between the various study groups (Tables 27 and 28). For each virus included in the survey, the level of antibody for each quarter was tested and the increases in antibody titers between quarters were compared. These comparisons must be multiplied by the number of viruses tested and the number of cities included in order to determine the total number of comparisons made. Therefore, there were 310 comparisons made in the initial survey and 153 in the final survey. Randomly, one would expect one in 100 to be significant at $p \leq .01$ and one in 20 to be significant at $p \leq .05$. The numbers and types of observed differences are shown in Tables 27 and 28. The direction of the differences (whether or not a study or control group had higher antibody levels of more increases in antibody) is also listed. It is apparent from this data that the serologic surveys did not demonstrate evidence of a marked increase in enterovirus infections in the wastewater workers.

Table 27. Results of the Initial Viral Serosurvey

Comparisons: 310 comparisons between groups (31 viruses x 5 comparisons x 2 cities)
Differences: 12 significant at $p \leq .05$ (5 at $p \leq .01$)
A) 10 differences in level of antibody
Control group higher in 5, both a control and study group in 2, and study group in 3
B) 2 differences in changing antibody titers
Study group higher for both

Table 28. Results of the Final Viral Serosurvey

Comparisons: 153 comparisons between groups (17 viruses x 3 comparisons x 3 cities)
Differences: 8 significant at $p \leq .05$ (3 at $p \leq .01$)
A) 7 differences in level of antibody
Control group higher in 1, both a control and study group in 2, and 2 study groups in 4
B) 1 difference in changing antibody titer
More increases in 1 study group, fewer in 2

The prevalence of antibody to Hepatitis A, as measured by radioimmunoassay, was also determined (Table 29). The prevalence of Hepatitis A antibody was not increased in workers as compared to controls. However, the number of study participants who were susceptible to Hepatitis A at the beginning of the study was not determined. Before we can conclude that Hepatitis A is not an occupational risk for wastewater workers, the actual number of workers at risk in each study group, as well as the number of infections which occurred during the study years, must be specified.

Family Study

The final aspect of this study was a serologic survey of viral antibodies in study participants and their families. The question was whether or not workers introduced viral infections into their families. A total of 128 families were studied, including 87 families of wastewater workers and 41 control families. Antibody was measured for six viruses, including Polioviruses 1, 2, and 3, Echovirus 9, Coxsackie A9, and Hepatitis A. These were selected because of the prevalence of viruses in wastewater and in workers, the frequency of poliovirus antibody expected in immunized children, and our interest in the possibility that Hepatitis A may be acquired by exposure to wastewater.

If the wastewater workers were being infected at work and introducing infection into their homes, then we would expect the antibody prevalence or antibody level to be higher in workers as compared to other members of their families and higher in family members of workers as compared to family members of controls. However, the serologic survey showed no significant differences between the various groups.

Table 29. Prevalence of Hepatitis A Antibody as Measured by Radioimmunoassay

Worker group	No. of workers	Number with Hepatitis A antibody	%
Inexperienced sewer maintenance	12	7	58.3
Experienced sewer maintenance	60	40	66.7
Inexperienced sewage treatment	140	42	30.0
Experienced sewage treatment	108	50	46.3
Controls	177	102	57.6

Summary

This preliminary report of the results of our study failed to show an increased risk of infection among wastewater workers. There was no consistent evidence of increased parasitic, bacterial, or viral infections as indicated by stool examinations, cultures, or antibody surveys. Liver function tests and immunoglobulin determinations also failed to show clinically significant or consistent abnormalities in the study groups. We did observe an increase in minor gastrointestinal illness among inexperienced sewage-exposed workers as compared to experienced workers and controls. These illnesses occurred most often in the second quarter of the year and did not correspond to enteroviral infections. Continuing studies will attempt to identify the cause of these illnesses.

The complete data on which these conclusions are based will be available in the final report to the Environmental Protection Agency.

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DISCUSSION

MR. BEARDSLEE: When you said that inexperienced sewage-exposed workers displayed higher incidence of gastrointestinal illness when compared to the various other groups, was this for both aerosol and waste-exposed workers?

DR. LINNEMAN: Yes, that was for the combined groups.

MR. BEARDSLEE: Those coming in direct contact with sewage were included in that category?

DR. LINNEMAN: That is right. The point of our concern, to expand on that a second, was whether or not the gastrointestinal illnesses occurred only in the early phases of employment. A preliminary look at the data suggests that, indeed, this is not the case. These are not illnesses occurring only in the first few weeks of exposure. They are distributed over the first half year or so of employment.

DR. FLIERMANS: I am interested in your *Legionella* findings. The 35% that you expressed, is that combined from all three cities, and are there differences among those cities?

DR. LINNEMANN: They were looked at for each city, and I simply combined them because there were no significant differences among the cities themselves.

DR. FLIERMANS: At a 128 level which CDC uses, what was that percentage?

DR. LINNEMANN: I think it was about half of what you saw on the figure.

DR. FLIERMANS: What were the serogroups that were used to measure IFA?

DR. LINNEMANN: These preliminary studies were only with serogroup I. Antigens are now available for serogroup II but we have not looked at them. We plan to in the future.

DR. PHAIR: There is a degree of cross reactivity that might be manifest in titer differences, but you would still have positive and negative reactions.

DR. WARD: The percentage of persons that have antibody to hepatitis A seems unusually high at 30 to 67%. Is that something that is related to socioeconomic class?

DR. LINNEMANN: It is related to socioeconomic class, and I think you see figures like this in a number of other surveys that looked at similar populations.

DR. WARD: So, for instance, would the upper middle class be around 10%?

DR. LINNEMANN: There have been surveys in those populations that have been that low, yes.

DR. WARD: So, actually, by examining sewage workers, you are examining a special class of people and persons, for example, in a higher socioeconomic group might be more of a risk if they were exposed to the same type of material as the sewage workers are exposed?

DR. LINNEMANN: Absolutely.

DR. RYLANDER: Concerning the gastrointestinal symptoms, they, by your description, fit exactly into the type of symptoms that we observed in our studies. However, we made an observation where we divided the employees into those who had a low exposure level, because they encountered sludge dust only occasionally when it was airborne, as compared with those who had a high exposure level because they were continuously exposed. We had symptoms in both groups which included intestinal trouble and high IgG. Those who went in occasionally were more affected than those who stayed in the foulest part continuously. I wonder if you had similar observations?

DR. CLARK: We haven't compared that yet; we will soon, though.

Worker Exposure to Organic Chemicals at an Activated Sludge Wastewater Treatment Plant

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ABSTRACT

During a seroepidemiological study concerned with evaluating the potential health risks of workers involved in the treatment of municipal wastewater, it was observed that the treatment plant had a characteristic and irritating odor which might be attributed to chemical wastes. The treatment plant is located near a manufacturer of pesticides and flame retardants. The potential exposure of treatment plant workers to the chlorinated organics and insecticides from this manufacturer prompted an investigation to discern whether these substances were present in the influent wastewater and in the air. Individual exposures were also estimated by personal air monitoring and by measuring urinary excretion of selected chlorinated organics.

Influent wastewater and area air samples were collected at various locations in the treatment plant from May through November 1978. Both influent wastewater and the workplace air contained substantial quantities of hexachlorocyclopentadiene (HEX) and several other chlorinated organics including hexachloronorbornadiene (HEX-BCH), heptachlorobicycloheptene (HEX-VCL) and chlordene. Typical concentration ranges for influent wastewater were: HEX (0.3 to 4 ppb), HEX-BCH (10 to 430 ppb), HEX-VCL (15 to 720 ppb) and chlordene (0.3 to 2000 ppb). The highest concentration of these substances in the ambient air at several locations in the treatment plant was 280 $\mu g/m^3$ for HEX-BCH. Further assessment of occupational exposure to these substances was indicated by their presence in urine specimens collected from workers at the end of the shift.

During a prospective seroepidemiological study aimed at evaluating the health risks from bacteria and viruses associated with the treatment of municipal wastewater, an opportunity developed to investigate exposure to organic chemicals emitted from the wastewater during the treatment processes. In the early part of 1978, workers at one of the wastewater treatment facilities being studied complained of acute symptoms of respiratory distress, dizziness, headache, and irritation of the eyes, throat, nose, lungs, and skin. It was also noted that the plant had an unusual and characteristic odor which was similar to what might be expected from industrial chemical wastes. The incidence of acute symptoms seemed to be associated with periods of more intense chemical odor. Although it has been generally recognized that workers in sewage treatment plants may be at an increased risk of exposure to infectious agents (1), only recently have studies revealed incidences of exposure of sewage treatment plant workers to potentially toxic chemicals.

The symptoms reported by the workers in this study were similar to those experienced by workers approximately a year earlier at the Morris Foreman Wastewater Treatment Plant in Louisville, Kentucky. In that incident, exposure was determined to be from pesticide intermediates, hexachlorocyclopentadiene (HEX) and octachlorocyclopentene (OCTA), which were illegally dumped into the municipal sewer system (2).

The wastewater treatment plant involved in the infectious disease study, and subsequently in this study, was the North Wastewater Treatment Plant in Memphis, Tennessee. This is a relatively new plant, and it is located near a manufacturer that produces and utilizes several chlorinated organic intermediates for the synthesis of flame retardants and pesticides (notably isodrin, endrin, chlordane and heptachlor). Waste from this manufacturer is discharged into a sewer that flows to the Memphis North Treatment Plant. Concern of potential exposure of treatment plant employees to toxic levels of chlorinated organics prompted an investigation to discern whether exposure to such chemicals in this municipal wastewater treatment plant exists. For comparison purposes, a second plant in Memphis, the Maxson Wastewater Treatment Plant, was used. The sewer from the pesticide manufacturer is not connected to the Maxson Plant.

The initial objective of this study was to establish a baseline chemical exposure, if any existed, of wastewater treatment plant workers during normal operational conditions so that if a spill incident occurred, or when employees experienced acute symptoms, an assessment of a potential chemical exposure could be made. A secondary objective was to conduct environmental monitoring to determine: 1) if the influent wastewater contained selected chlorinated organic contaminants; and 2) if these substances were being released into the air during the treatment processes.

Experimental

The initial study carried out in May 1978 was designed to be a screening of urine specimens for HEX. The study was conducted at the time of the regular quarterly collection of specimens for the infectious disease study. Urine samples used in this survey were collected near the end of the work shift from workers at the North and Maxson treatment plants. The urine specimens were frozen immediately after collection and were kept frozen until analyzed. The analysis of urine involved extraction of urine with petroluem ether, after saturating the urine with NaCl. The petroleum ether extract was analyzed for HEX and HEX-BCH by gas chromatography using an electron capture detector. The analyses were performed with glass columns packed with OV-101 or OV17/QF-1 at 175°C.

The primary route of exposure of treatment plant workers to these substances is probably by inhalation. Therefore, it was important to determine the concentration of these substances in the ambient air in the treatment. Apparently, chemical wastes enter the treatment plant either in a soluble form or adsorbed to suspended materials in the wastewater. Aeration during the treatment processes causes aerial dispersion of these substances as aerosols and vapors.

Dispersion of organic contaminants into the ambient air was established by collecting area air samples at several locations in the treatment plant. Air sampling consisted of drawing air through glass sampling tubes containing 150 mg of preextracted Chromosorb 102 (3). Chlorinated organics were desorbed from the sorbent with petroleum ether and subsequently analyzed by gas chromatography using an electron capture detector (Ni^{63}).

Urine screening was again conducted during June and September 1978. Urine samples from both the start and end of the work shift were collected in June 1978. During the September 1978 screening, end-of-the-shift samples were also obtained from a Cincinnati, Ohio, wastewater treatment plant. Personal air monitoring of a group of workers at the Memphis plants was conducted in September 1978 both at their work site and while they were away from work. Ambient air and influent wastewater were monitored at various times from May to November 1978.

Results

Seventy-two workers participated in the first urine screening, 41 from the North plant and 31 from the Maxson (South) plant. The results of this survey are presented in Table 1. HEX was found in urine specimens for 25% of the individuals at the North Plant. HEX-BCH, more prominent than HEX, was found in 90% of the samples. Urinary concentrations of HEX-BCH were also higher than those of HEX.

Table 1. Analysis of HEX and HEX-BCH in Urine Samples Collected at the End of Shift in May 1978 (Memphis)

	HEX		HEX-BCH	
Plant	N_P/N_T[a]	Range µg/l	N_P/N_T[a]	Range µg/l
North	10/41	<0.8-2.5	37/41	<0.3-15.2
South	2/31	<0.8-1.4	11/31	<0.3-9.5

[a] N_P = number of samples containing the compound N_T = total number of samples

Figure 1 shows typical gas chromatograms of influent wastewater collected at the North and Maxson treatment plants during the time of this study. The North plant sample clearly shows the presence of several contaminants including HEX-BCH, heptachlorobicycloheptene (HEX-VCL) and chlordene. In comparison, the influent samples at the Maxson plant do not contain these types of contaminants. Although the presence of several contaminants in the wastewater is indicated, they would have to be emitted into the air as aerosols or vapors before significant exposure to workers would occur.

Gas chromatograms of area air samples collected at the wet well and grit chamber of the treatment plants are similar in appearance to the chromatograms of the wastewater. These samples showed that HEX,

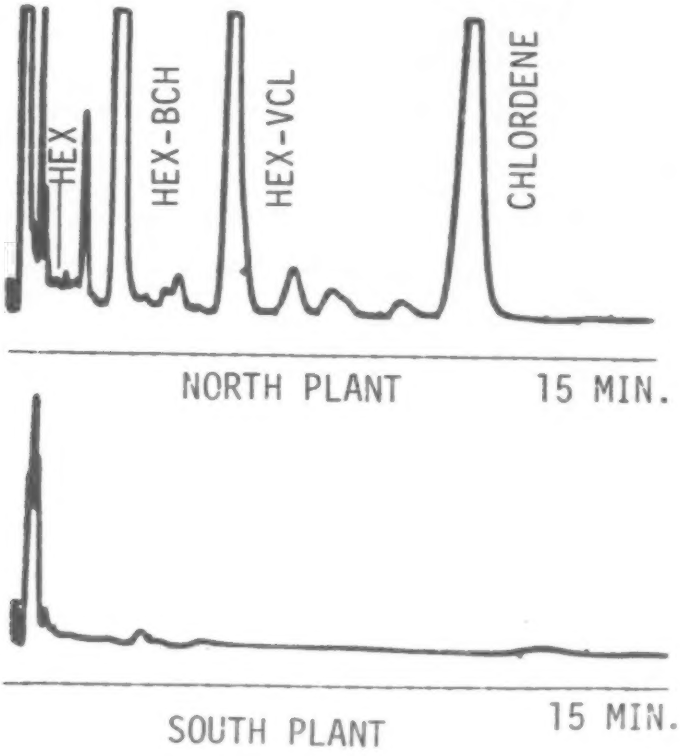

Figure 1. Gas Chromatograms of Extracts of Influent Wastewater Samples

HEX-BCH, HEX-VCL, and chlordene were present in the atmospheric air at the Memphis North Treatment Plant and indicate that the source was aerial dispersion from the wastewater. Air samples have also been obtained at the grit chamber of the Maxson Plant and the Mill Creek Treatment Plant in Cincinnati, Ohio. These chromatograms had several early eluting peaks suggesting the possible presence of some volatile chlorinated hydrocarbons. However, there was no indication of the substances found in the samples obtained at the Memphis North Plant.

The concentrations of four chlorinated organics found in the influent wastewater of the Memphis North Plant during the time of air sampling and urine screening studies are given in Table 2. Although these values do not represent the values for the complete month, they are indicative of the concentrations at various times. The concentration of HEX-BCH was generally about 300 ppb, although much lower levels were measuring during October and November. HEX-VCL and chlordene concentrations seem to be more variable, ranging from about 17 to 2000 ppb.

Table 2. Influent Wastewater at Memphis North Treatment Plant, 1978

	Concentration, μg/l			
Date	HEX	HEX-BCH	HEX-VCL	Chlordene
June	3	334	57	87
August	<0.8	329	115	216
September	4	292	668	58
October-November	<0.8	11	17	32

One sample collected during September had a chlordene concentration of 1980 ppb. The September samples listed in Table 2 were collected at the time of a reported spill which occurred subsequent to the urine screening that month. The analysis of wastewater and air samples indicated that HEX-VCL was at least one of the major constituents in the spill.

Area air samples collected at various locations in the treatment plant provide an indication of the magnitude of aerial dispersion of these semivolatile compounds. The concentrations of these substances found in air samples collected in the wet well, which is a building with a ventilation system, and the grit chamber are presented in Table 3. The levels at the wet well are generally higher than at the grit chamber. HEX was found at levels as high as 39 μg/m³. The highest levels of HEX-BCH and HEX-VCL measured were 280 μg/m³ and 200 μg/m³, respectively.

Table 3. Area Air Samples Collected at the Memphis North Plant, 1978

		Concentration, μg/m³			
Location	Date	HEX	HEX-BCH	HEX-VCL	Chlordene
Wet well	May	<0.03	219	87	45
	June	18	278	15	16
	September	8	25	200	44
	October	15	2.4	1	<0.14
	November	39	6.8	85	7.8
Grit chamber	May	<0.03	4.1	1.9	0.9
	June	6.3	65	1.5	5.3
	July	<0.03	0.5	0.7	2.3
	September	0.02	0.5	1.1	2.7
	October	0.04	1.2	1.0	0.8
	November	12	2.6	4.3	1.0

Since the initial urine screening conducted in May 1978 revealed the presence of at least two compounds (HEX and HEX-BCH) in a number of urine specimens, a follow-up urine screening was conducted in June 1978. In this study, urine specimens were collected early in the work shift (beginning of shift) and a second specimen was collected near the end of the work shift. This sampling strategy was undertaken to investigate the relationship between exposure and the appearance of these chemicals in urine. The results of this study are summarized in Tables 4 and 5. A number of the urine samples obtained early in the work shift (Table 4) had detectable amounts of both HEX and HEX-BCH. However, in the case of North plant samples, some exposure could have

Table 4. Urine Samples of Wastewater Treatment Employees Collected During the First 4 Hours of the Shift in June 1978 (Memphis)

	HEX		HEX-BCH	
Plant	N_P/N_T[a]	Range µg/l	N_P/N_T[a]	Range µg/l
North	11/56	<0.8-3.7	18/56	<0.3-7.5
South	5/24	<0.8-4.8	10/24	<0.3-12

[a] N_P = number of samples containing the sample N_T = total number of samples

Table 5. Urine Samples of Wastewater Treatment Plant Employees Collected at the End of Shift in June 1978 (Memphis)

	HEX		HEX-BCH	
Plant	N_P/N_T[a]	Range µg/l	N_P/N_T[a]	Range µg/l
North	5/53	<0.8-3.1	41/53	<0.3-10.3
South	5/18	<0.8-3.9	2/18	<0.3-1.6

[a] N_P = number of samples containing the compound N_T = total number of samples

occurred prior to obtaining the specimens. The HEX-BCH concentrations for the Maxson (South) plant samples had one high value of 12µ g/l which was much higher than the other samples. The values for the other nine samples ranged from 0.4 to 3.5 µg/l, while the values for the North plant sample ranged from 0.4 to 7.5 µg/l. End of the work shift samples (Table 5) indicated that urinary excretion of HEX-BCH increased during the work shift for individuals at the North plant. Thirty-two percent of the early-in-the-shift samples had detectable concentrations of HEX-BCH. This increased to 77% for the end-of-the-shift samples; the means for these was 4.1 µg/l.

Of 43 paired urine samples at the North plant, one each at the beginning and end of the shift from the same individual, 34 increased during the shift for HEX-BCH while three decreased and six were below detectable limits both times. This contrasts with the Maxson (South) plant results where only two increased in HEX-BCH concentration, seven decreased, and nine pairs were below detectable limits. For HEX concentrations, 32 paired urine samples from the North plant workers were below detectable limits, four increased, and eight decreased. At the Maxson plant, 12 pairs were below detection each time, three increased, and three decreased.

The data, presented in Table 6, give the results for a urine screening conducted in September 1978 at the time of the regular quarterly specimen collection. One individual at the North plant had a detectable concentration of urinary HEX-BCH. HEX was not found in any of the North plant samples and neither HEX nor HEX-BCH was found in the samples of individuals from the Maxson (South) plant. Urine samples were also collected from a wastewater treatment plant in Cincinnati to serve as a control. Air samples collected at the North plant at this time (Table 3) showed that the concentrations of airborne chlorinated organics were considerably lower than those found in May and June.

Table 6. Urine Samples of Wastewater Treatment Plant Employees Collected at the End of Shift in September 1978

	HEX		HEX-BCH	
Plant	N_P/N_T[a]	Range µg/l	N_P/N_T[a]	Range µg/l
North (Memphis)	0/49	—	1/49	0.8
South (Memphis)	0/23	—	0/23	—
Mill Creek (Cincinnati)	0/21	—	0/21	—

[a] N_P = number of samples containing the compound N_T = total number of samples

Personal air monitoring of 11 workers at the North plant was carried out in September 1978. Eight-hour personal air samples were collected during the work shift and during the workers' off-shift time (home sample). The work shift sample for most of the North plant workers contained HEX, HEX-BCH, HEX-VCL and chlordene. There was no obvious relationship between work area and the extent of exposure. Several of the home samples also had detectable amounts of some of these compounds, but the levels were considerably lower than the work shift sample. The air concentrations for the four compounds found from personal air monitoring were in good agreement with the concentrations determined from area air samples collected at the grit chamber. The samples of the workers at the Maxson plant were below detection limits except one work shift sample which contained a trace of HEX-BCH.

The source of the organic chemicals found in urine specimens and occasionally in air samples from the Maxson plant is not well understood. Possibilities include: intermittent discharge into the sewer system by either a user of these chemicals or a waste hauler; discharge from a buried dump site containing these substances; and ambient air pollution in the Memphis area. It is clear from the data collected during the study that these compounds are not present at the Maxson plant at the same levels as the Memphis North plant, nor do the positive values seem to be associated with working at the Maxson plant, since paired urine samples at the beginning and end of the work shift do not increase in concentration of the chemicals.

Discussion

It is generally recognized that wastewater treatment plant workers are exposed to a wide variety of infectious agents. Only recently has it become apparent that these workers are also exposed, at times, to toxic chemicals. In industrial operations, control measures can usually be instituted to minimize worker exposure and atmospheric release of toxic contaminants. However, wastewater treatment facilities, with their many open tanks and basins, generally are not designed so that aerial dispersion of contaminants can be eliminated. Furthermore, the nature and quantity of chemicals in the influent wastewater are usually highly variable and generally unknown. In many systems, aeration of the wastewater is a vital treatment process, but this also causes increased aerial dispersion of certain chemical contaminants as aerosols and vapors.

Hexachlorocyclopentadiene is a semivolatile compound which is only slightly soluble in water. Inhalation, dermal, and oral exposures of HEX have been reported to cause several short-term and toxicological symptoms. Animal studies have indicated that long-term exposures may result in a number of nonspecific adverse health effects (4). In 1977 a threshold limit value (TLV) of 110 $\mu g/m^3$ was recommended by the American Conference of Governmental Industrial Hygienists (5). TLV's have not been established for the other compounds, but there are indications that HEX-BCH may be as toxic as HEX. Hypothetically, if it is assumed that the TLV for HEX-BCH would be equal to the TLV for HEX (110 $\mu g/m^3$ or 10 ppb), air concentrations measured in the wet well during May and June 1978 would be about two times this TLV level. In practice, when evaluating air exposure levels for two or more hazardous substances, the effects of those substances should be considered additive unless other information is available. This practice implies that for complex exposure situations, i.e., those that might be encountered at wastewater treatment facilities, determination of exposure levels of a single chemical may not adequately reflect the actual exposure burden experienced by an individual. In this case, consideration of the exposure levels of several substances is recommended.

The Louisville, Kentucky, episode demonstrates a case of acute exposure to toxic contaminants from wastewater. The situation described in this paper is a case of essentially continuous chronic exposures with intermittent acute exposures. Unfortunately, only limited information is available on the toxicity and health effects of these chlorinated organics. Thus, the significance of urinary excretion of these substances and the possible relationship to health effects are not known.

Acknowledgement

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DISCUSSION

DR. PHAIR: In the past two or three years, there have been publications about the inhalation of chlorinated hydrocarbons, ring compounds, thallic anhydrides, and compounds of that nature in the chemical industry. Certain numbers of workers have been shown to have respiratory symptoms, and other groups have been shown to have an allergic asthmatic type of disease.

One approach to this problem has been to use a reactive chemical as a hapten, bind it to protein carriers, and then look for antibody in the workers. I wonder if you have thought about this approach in getting a handle on health effects, especially in those individuals who seem to have a chronic exposure because of their environment?

DR. ELIA: We have not tried anything like that.

MR. COLLINS: First of all, I want to thank Dr. Clark and his associates for the studies they did in bacterial and viral problems and in pesticides at our Memphis sewage treatment plant. I have a question which you can clear up for me. Since HEX and HEX-BCH have relatively good absorption abilities, what is the possibility that these compounds could have been absorbed by NaCl during the testing preparation and given erroneous results?

DR. ELIA: This has been looked at and considered. At the time when we ran our urine specimens, we ran blanks which included carrying urine through the complete process and using all of the reagents. At that time, we did not have any traces of contaminants in the areas of HEX or HEX-BCH in our chromatograms. We have received a sample of the salt. Those salt samples were also analyzed 3 or 4 weeks after our studies, and I am sure that if it had been left open for a period of time it certainly could have picked up contamination, especially if there are levels of these compounds continuously in that environment.

Our analysis of the salt samples, which you referred to, does not show any indications of HEX or HEX-BCH. We have done this in Cincinnati. I also have chromatograms that were run on those salt samples from the chemist at the Memphis North Treatment Plant; and those chromatograms do not show any traces of HEX or HEX-BCH, but do show traces of HEX-VCL and a little bit of chlordene. The amounts that they used in their samples were probably larger, maybe at least two or three times the amounts which we normally used in our extraction of the urine samples. Also, a number of these samples run during that time did not show any presence of these compounds; and, if there was actually contamination, you would expect it throughout all of the samples.

MR. COLLINS: I want to thank you.

Disease Rates Among Copenhagen Sewer Workers

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ABSTRACT

Sewer workers in Copenhagen, Denmark, have a higher death rate than the comparable male population. An alarmingly high proportion of the deaths occur within the year that employment terminates. Attempts to correlate the statistics with sick leave records or chemicals in the environment have not been successful so far. Sewer workers experience a high rate of gastrointestinal tract disorders which they associate with chemical odors and infectious agents. They have elevated levels of gamma globulins. Analytical work has not yet identified any agents that might be responsible for the observed death rates or the gastrointestinal problems. Biological examinations of stool specimens have not been made.

The health of sewer workers has been discussed in the literature for at least the past 25 years (1). There is no doubt that sewer workers are exposed to a relatively high level of enteric pathogenic agents in the course of their work. In industrialized countries, there is also potential exposure to chemical vapors such as benzene and other solvents used in paints and manufacturing. Attempts to relate exposure to disease rates have seldom shown statistically significant effects. In fact, some anecdotal reports have claimed that sewer workers had lower rates of absenteeism than control groups (2). This was explained on the assumption that the sewer workers got protective immunization doses of infectious agents and thus developed resistance to more serious infections.

The health and working conditions of sewer workers in Copenhagen have been investigated and reported in a series of documents published and discussed over the period 1975 through 1977. In April 1974, the union representing the sewer workers requested the University of Copenhagen to investigate environmental and health problems of Copenhagen's sewer workers. The study was assigned to J. Mørkholdt Andersen and Tage Egsmose, M.D., associate professors at the University's Institute of Hygiene. Some financial assistance was provided by the municipality from the sewer department's budget.

The preliminary report came out in December 1975, and was published with minor corrections in April 1976 (3). Additional death statistics were presented later (4), and sick leave data were provided by the municipality (5) as a response to the original preliminary report. In April 1977, a second report was published based on medical consultations with sewer workers (6). A report of blood and urine chemistry was issued in 1977 (7). The data in these reports have been summarized in a U.S. EPA report (8) which forms the basis for this paper.

The municipality of Copenhagen serves 600,000 permanent residents, approximately 200,000 transients and commuters, and has an industrial load equivalent, on a BOD_5 basis, to 1,600,000 additional persons for a total equivalent load of 2.4 million. The sewage is strong, on the order of 750 mg/l BOD. At the present time sewage is screened to remove rags and large objects and discharged through two outfalls directly to the waters between Copenhagen and Sweden. A modern treatment plant using high rate activated sludge with the UNOX pure oxygen process is under construction and is expected to go into operation in late 1979. One small plant uses primary treatment and digestion. Over the entire period covered by the reports, sewer work involved primarily cleaning and maintenance of sewers, manholes, screens, and pump stations. It did not include sewer construction or mechanical shopwork such as repairing motors and pumps. About 80 permanently employed workers were classified as sewer workers in 1976. Management of the sewers is a division of the City Engineer's office. The sewer workers are members of the Earth and Concrete Workers Union and the Highway Department Workers Club.

"The Sewer Workers Report" (3) is based on four separate studies:

- responses to a questionnaire given to sewer workers about health and working conditions
- a study of sick leave records from January 1957 through December 1973 for sewer workers and a control group of all city office workers
- a study of death records compared with national mortality statistics
- assessment of reports of analyses of sewer atmospheres for toxic substances.

The report "Sewer Work and Health" (6) is based on clinical consultations with 82 out of 97 sewer workers in 1976. The same group and two control groups were subjected to a battery of tests on blood and urine (7,9). The reports are considered together.

Questionnaires and Sick Leave Records

Responses to the questionnaires as well as the medical consultations clearly show that sewer workers consider their job to be unhealthy and unsafe. A detailed analysis of the responses to the questionnaires is not included because the responses are difficult to reproduce and are liable to be influenced by local customs and recent news items concerning the environment. Sick leave records are also difficult to analyze because the decision to take sick leave is made by the worker. In Denmark, sick leave pay for permanently employed municipal workers is 100% of base pay but does not include extra pay for "dirty work." Medical confirmation of short illness is seldom required.

Table 1 compares sick leave for permanently employed sewer workers over the period 1959 to 1973 with male office workers of comparable ages in the year 1964. At all ages above 30 years, the sewer workers take more leave than office workers. Most significant is the high percent of sick leave taken by sewer workers over 50 years of age. Workers over 60 years of age take an average of 1 day in 5 as sick leave.

Table 1. Sick Leave for Sewer Workers and City Office Workers (3)

	Sewer workers (1959-1973)		Office workers (1964)	
Age	Sick days	%	Sick days	%
24 - 29	71	0.7	855	1.5
30 - 39	2,100	4.0	1,755	1.6
40 - 49	3,362	5.6	4,667	2.7
50 - 59	2,426	9.2	7,756	3.9
60 - 69	623	20.1	9,952	5.4

A rebuttal from the City Engineer's Office (5) gives the comparative sick leave data shown in Table 2; unfortunately no age adjustment.

There are relatively few transfers between work groups. The high sick leave of garden and park workers is attributed to hazardous working conditions, as in trees, rather than a selection of older workers for garden and park work. There is no evidence that sewer workers take more sick leave than other manual workers although sewer workers certainly take more sick leave than office workers.

Table 2. Sick Leave Rates of Unskilled Wage Earners in the City Engineer's Office, Not Adjusted for Age

	1973(%)	1974(%)
Parking meter collectors	6.1	6.5
Street cleaners	7.1	7.3
Sewer workers	7.6	8.8
Street repairmen	8.1	9.4
Garden and park workers	10.6	10.9
Workshop and warehousemen	10.3	12.2

The second study (6) was recommended by the authors of the first report (3), and was financed by the municipality to investigate health problems among sewer workers. Matched control groups from the city gardeners and from office workers were chosen by the municipal personnel office, and their blood and urine chemistry were determined (7,9); however, not enough money was supplied for a medical examination of the controls. This report confirmed the questionnaires of the first report and concluded that sewer workers have a higher than normal incidence of acute symptoms of gastrointestinal disorders including nausea, vomiting, and diarrhea. It further concluded that the disorders are directly related to the intensity of exposure to sewer odors and splash. Half of the workers have had diarrhea in the past year, and 10% say they have experienced it one or more times a week. The frequency of the disorders is related to current exposure and not to years of experience. Few workers go to their doctors for treatment for gastrointestinal disorders but seem to consider them to be part of the job. No examinations of stool specimens were made. The doctors concluded that sewer workers have a high level of chronic problems including fatigue, difficulty in concentrating, headaches, and dizziness, as well as psychic problems. The doctors making the 81 examinations found 21 cases of occupational disease which were reported to the health service doctor. An additional

25 cases were not reported because the workers did not wish it.

Many workers consider that odors rather than infectious agents cause their gastrointestinal disorders. For example, one told the doctor, "Suddenly you get this stench in the face, and then you know you will have stomach trouble for the next few days." (6) In a publication from the Occupational Health Office, a steward said, "Longer vacations are necessary because we have a very special problem getting accustomed [to the sewer environment]. After a vacation of a week or more, one is almost always sick the first two or three work days with vomiting, nausea, headaches, and smarting of the eyes. We don't know what we owe it to, but it is most likely the chemicals in the sewer." (6)

Analytical Data

The chemical analyses reviewed (3) provide no evidence for toxic chemicals that might be related to acute gastrointestinal problems. Solvent vapors occasionally exceeded hygienic standards for 1 hour's exposure and H_2S once reached 13 ppm versus a standard of 10 ppm. There is little doubt that industrial discharges frequently contribute high levels of organic vapors to the sewer, contrary to regulations. Many of these discharges are of short duration and are, therefore, difficult to identify. The effect of these vapors on the health of sewer workers is at present only conjecture. One station was found to have three times the allowable level of benzene when a sick worker was replaced (6). There was, however, no diagnosis of benzene toxicity in the sick man. One case of high lead in the blood was found in a worker who had been cleaning heating coils in a sludge digester (6). The job was very dusty and the dried sludge had a Pb content over 100 mg/kg. The worker was transferred to another job and his blood Pb levels returned to the normal range. Masks are specified for workers in dust or spray, but the worker may not have been using his mask effectively. The second study (6) includes photographs of a worker who was using a high pressure spray to clean screens but was not using a mask, and of another worker who was not using his gloves to handle a wooden ball used to clean the sewer, again contrary to regulations.

The report of clinical laboratory analyses (7) showed little essential difference over a wide range of chemical parameters between sewer workers and the control groups chosen by the personnel office. In many cases the sewer workers, as a group, fell between office workers and garden workers. In a follow-up study (9) a significantly higher level of the immunoglobulin, IgG, was found in the sewer workers but no significant differences from the control group for IgA or IgM. Higher levels of antibodies to hepatitis A were also reported for the sewer workers but no difference in antibodies to hepatitis B, otherwise known as serum hepatitis.

Death rates among sewer workers

The initial study (3) showed 24 deaths among 142 sewer workers who had been employed for at least one year in the period 1957 through 1973. This is significantly greater than the death rate for all Copenhagen males of comparable ages. An updated report (4) added nine additional deaths that had not been available to the authors at the time of the original study. Table 3 groups the workers by years of employment and shows the comparable death rates for Copenhagen males based on the 1975 statistical yearbook. Death rates in Copenhagen do not change very much from year to year.

Table 3. Death Statistics for Sewer Workers

Years of sewer work	No. of deaths (N)	Expected deaths (E)	$(N-E)^2/E$	Probability (%)
1-8	8	9.8	0.3	
9-12	14	5.8	11.6	0.1
13-16	11	5.6	5.2	2
Chi square			17.1	0.5

Workers who have spent 1 to 8 years in sewer work in the 15-year study period have a death rate indistinguishable from the city rate. For the next 8 years of employment, the rate is more than twice the expected rate. A statistical analysis of the data shows the following: The chi-squared test on the three groups, 1 to 8 years, 9 to 12 years and 13 to 16 years, is highly significant. Individual groups were tested against the Poisson distribution. Death rates for workers with 9 to 12, and 13 to 16 years of employment were significant at the 2% level or better. Therefore one can conclude that workers who have spent more than 8 years in Copenhagen sewers have about twice the death rate of all Copenhagen males. The normal death rate during the first 8 years of employment may also reflect an adverse environment since sewer workers are selected from healthy able-bodied males who should have a death rate significantly below the city average (11).

When the causes of death of the 33 cases were examined, the only outstanding difference from the national average was for cancer of the pancreas. Of nine cases of cancer recorded on the death certificates there were three cases of cancer of the pancreas, two cases of lung cancer, and one each for four other cancers. The expected death rate is only 0.4 cases of pancreatic cancer among 33 deaths of men over 25 years of age. The apparent Poisson probability is 0.8% that three deaths from pancretic cancer will occur. However, as pointed out by Tukey (12), the apparent probability of a chosen high-incidence level must be multiplied by the number of possible choices that could have been made had the incidence been high in any one of them. In this case, there were six types of cancer and many other causes of death, so the probability level is at least 6 times 0.8%, or 4.8%, which is barely significant. The death certificates have been examined further for other possible correlations, but none have been reported. It was found that one of the three victims of pancreatic cancer had been employed less than 2 years in sewer work followed by other employment.

Over 40% of dead former sewer workers died within the calendar year in which they stopped working (3). The calculation is based on 210 sewer workers of whom 111 left the work force in the years 1959 to 1973. Thirty-two of these had died by the end of 1976; 13 of them in the year that employment terminated. The ages at death of 12 of the 13 men who died in the year that employment terminated were evenly distributed between 51 and 68 years. Some of these men were ill when they stopped working. Put another way, 12% of the former workers died in the calendar year in which they terminated work. For comparison, only 1% of Copenhagen males aged 55 and 3% of those aged 65 will die within the twelve months following their respective birthdays. Although it is well known that retirement increases the risk of death, it is more likely that the causes of death of most of the 13 men were related to the condition of their health before termination of their employment. It is also known that manual laborers in some industrialized countries have a higher death rate than the general male population. Unfortunately, comparative death statistics for other groups of workers in Copenhagen have not been analyzed.

Conclusion

Mortality statistics show that sewer workers die earlier than Copenhagen males of comparable age, many of them soon after termination of their employment. The sewer workers complain of nauseating odors and a high incidence of gastrointestinal tract disorders. They have elevated levels of gamma globulin but no other significant differences from control groups. The available evidence is insufficient to assign cause for their poor health and reduced life expectancy. It seems probable that biological and chemical insults, caused in part by lax observance and poor enforcement of safety regulations and discharge restrictions have all contributed to the adverse survival expectancy of this group.

In an attempt to reduce the discharge of solvents and other chemically hazardous wastes to the sewers, the City of Copenhagen has arrangements with 40 paint and household chemical retailers to collect containers of waste materials for eventual disposal by Kommune Kemi, Denmark's official organization for the disposal of hazardous wastes. The program is well advertised in the newspapers by posters and displays in the windows of cooperating dealers. The dealers also give out plastic carrying bags advertising the program. It is too early to evaluate the effect of this program on sewer workers' health, but the return of hazardous solvents has been very encouraging.

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Sewage Treatment Plant Workers and Their Environment: A Health Study

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ABSTRACT

A 1-year multidisciplinary study was conducted in two secondary sewage treatment plants. Sporadic and inexplicable peaks of H_2S approaching and, on occasions, exceeding acceptable levels have been detected in the grit tank areas. Intermittent excessive levels of CO_2 have been recorded in the secondary treatment areas. Bacteria and viruses were isolated from the samples of sludge, effluent, and air tested. The comprehensive hematological, biochemical, serological, and immunological profiles obtained on each of the 77 plant personnel at the beginning and at the end of the study showed few significant findings. Fecal examination revealed an inexplicable lack of gram-negative bacilli in some cases. No pathogenic bacteria or viruses were isolated from the throat swabs of personnel with upper respiratory symptoms. Employees' respiratory health status was assessed by means of a questionnaire and two lung function tests. Symptoms and abnormalities were more prevalent in smokers than in nonsmokers and were comparable, in both groups, to those found in general population. Sinusitis was the most common complaint, indicating an upper airway problem caused by a yet undetermined irritant, allergen, or infectious agent. This and other symptoms invariably started upon exposure to the work environment and improved upon leaving it, thus producing illnesses of short duration.

Concern about the health hazard of the work environment was expressed by employees and management of two sewage treatment plants in Winnipeg. By mutual agreement, it was decided that all employees would participate in a health study sponsored by the city.

The objectives of the study were:

- to assess the health hazard of the work environment
- to assess the health status of the employees

- to determine any relationship between health hazard and health effects
- to recommend relevant corrective measures, if any.

A multidisciplinary study was therefore designed to:

- evaluate the work environment by means of a chemical and microbiological industrial hygiene survey
- assess the employees' health by means of a questionnaire, clinical examination, lung function tests, recording of sickness, and an extensive set of laboratory tests performed on feces and blood
- test sick employees.

INDUSTRIAL HYGIENE CHEMICAL SURVEY

The north plant provides secondary sewage treatment for the largest part of the metropolitan area of Winnipeg. It consists of: grit removal and preaeration, primary treatment (clarifiers), and secondary treatment (totally enclosed building). The raw and the activated sludge generated are treated by anaerobic digestion and then pumped to sludge-drying beds in the area. The average dry weather flow is approximately 60 million imperial gallons per day (migd).

The south plant has been designed to serve the southern part of the city. Its sewage flow is approximately 10 migd with provisions for expansion to 35 migd. This particular facility is unique in that it is the first plant in Canada, and one of the first in North America, to use pure oxygen (95%) generated on site for the biological treatment of sewage.

Table 1 shows the results that were accumulated during the health study period by *continuous* monitoring of H_2S, temperature, and humidity. Monitoring was carried out in all four seasons of the year, but significant seasonal variations were not noted. H_2S concentrations were readily detectable in the preaeration building of the north plant and in the preaeration and primary treatment buildings of the south plant. Of particular concern is the preaeration building at the north plant where we detected unexplainable slugs of H_2S exceeding the threshold limit value of 10 ppm.

Table 1. Continuous Monitoring Results—North and South Plants

Location	H_2S (ppm)	Temperature (°F)	Humidity (%)
Preaeration and grit removal			
North plant	[a] to >10	55–74	34–96
South plant	[a] – 3.8	63–80	32–80
Primary treatment			
North plant	[a]	56–80	38–96
South plant	[a] – 2.5	54–69	52–99
Secondary treatment			
North plant	[a]	63–80	57–90
South plant	[b]	[b]	[b]

[a] Not detectable

[b] Not done

Table 2 shows results accumulated on a *spot* monitoring basis for H_2S, CO_2, CO, NH_3, and for the following heavy metals: Ni, Pb, Cu, Zn, and Cd. The H_2S levels detected were very similar to those found using continuous monitoring equipment. Elevated CO_2 concentrations were detected in the enclosed secondary treatment buildings at both plants. Other contaminants monitored, including heavy metals, were either not detectable or well below accepted standards.

Table 2. Spot Monitoring Results—North and South Plants

Location	H_2S (ppm)	CO_2 (%)	CO (ppm)	NH_3 (ppm)	Heavy metals Ni,Pb,Cu,Zn,Cd (mg/m³)
Preaeration and grit removal					
North plant	[a]–6	0.03–0.06	[a] 10	[a]	<0.02
South plant	[a]–2	0.025–0.08	[a]	[a]	
Primary treatment					
North plant	[a]	0.03–0.05	[a]	[a]	[b]
South plant	[a]–2	0.02–0.03	[a]	[a]	
Secondary treatment					
North plant	[b]	0.03–0.14	[a]	[b]	[b]
South plant	[a]	0.03–0.50	[b]	[b]	

[a] Not detectable
[b] Not done

INDUSTRIAL HYGIENE MICROBIOLOGICAL SURVEY

The work environment was also examined microbiologically by testing samples of air and sewage.

Microbiology of Air

Air samples were collected at the same arbitrarily selected locations as for the Industrial Hygiene Chemical Study. Settling plates containing enrichment medium were placed for 1 to 15 min, (depending on location and time of year) for the collection of bacteria. For the collection of viruses, an impinger was used, pumping 10 *l* of air/min into buffered saline. Standard laboratory procedures were used for the isolation and identification of microorganisms (1,2).

Table 3 shows that gram-positive bacteria were found predominantly in winter, in both pre- and secondary aeration areas. However, in the summer, more bacteria were isolated, and most isolates were gram-negative bacteria. The significance of this seasonal variation is not clear. The most common gram-negative bacteria isolated in the summer was *Aeromonas hydrophila. Salmonella* and *Shigella* were not isolated. The most interesting isolation was that of an atypical *Yersinia enterocolitica*, isolated in the summer from the preaeration area of the south plant. Two of the 13 air samples assayed yielded enteric viruses; both were collected from the secondary aeration area of the north plant. A poliovirus type 2 was isolated on an RD (3) cell line in winter, and an echovirus type 7 was isolated on a BGM cell line in the summer.

Table 3. Airborne Bacteria

	Plant	Season	Total no. isolates	Gram-positive bacteria (%)	Gram-negative bacteria (%)
Preaeration	North	Winter	1,452	77.1	21.5
		Summer	6,691	18.4	81.5
	South	Winter	215	54.8	45.1
		Summer	5,502	12.6	87.4
Secondary aeration	North	Winter	713	66.3	33.8
		Summer	1,699	9.8	90.1
	South	Winter	[a]	[a]	[a]
		Summer	800	18	82

[a] Not done

Microbiology of Sewage

Grab samples of raw and digested sludges and 24-hour composites of final effluent were examined by use of standard laboratory procedures (4).

The total and fecal coliform counts were reduced by the treatment to 5.0 to 8.3 and 5.0 to 7.7 ($\log_{10}$) colony forming units/l of final effluent, respectively. Counts were slightly higher in the spring. Coliforms were not tested for enteropathogenicity, enterotoxigenicity, or transferable drug resistance.

Fifty-four *Salmonella* were isolated from 38 samples of sludge and 16 samples of effluent, representing 13 different serotypes, shown in Table 4. All but two, *Salmonella thomasville* and *Salmonella london* have been identified from human feces in Manitoba. The most common was *Salmonella st. paul*, a serotype that has, in the last 15 years, always been listed among the 10 *Salmonella* spp. most commonly isolated from humans in Manitoba. It should be noted that *Salmonella typhi* was not isolated.

Table 4. *Salmonella* Serotypes Isolated from Sewage

Serotype	No. of isolates
S. st. paul	15
S. muenchen	10
S. infantis	8
S. typhimurium	5
S. newport	3
S. thompson	3
S. london	3
S. new brunswick	2
S. heidelberg	1
S. panama	1
S. blockley	1
S. enteritidis	1
S. thomasville	1

Interim Report on a Mortality Study of Former Employees of the Metropolitan Sanitary District of Greater Chicago

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ABSTRACT

In order to discover any adverse health effects among workers in the wastewater industry, a mortality study of workers who were employed at the Metropolitan Sanitary District of Greater Chicago during the 1960's has been undertaken. This interim report is based upon data from the complete employment records and death certificates of 402 decedents, approximately half of the expected number. Proportionate mortality analyses of these data have not shown any significant departures from expected death rates for several major disease groupings, for the workers as a whole, for several employee subgroups, or by length of employment.

Workers in the wastewater collection and treatment industry are exposed to a wide variety of conditions which may have an adverse effect on their health and well-being. These conditions result not only from the presence of infectious biological agents and hazardous chemicals in wastewater but also from physical hazards present in their workplace environment. The safety record of the wastewater industry has long been known to be one of the worst in this country (1). Most studies of the health of wastewater workers have focused on risks due to biological agents present in the wastewater. A review by Clark et al. (2) summarizes many of the earlier studies. More recent studies of this type by Rylander and Lundholm (3), Sekla (4), and Clark et al. (5) are reported elsewhere in this Symposium. The Sekla study and studies by Kominsky (6) and Elia et al. (7) also includes evaluations of some chemical exposures; these studies are reported in this Symposium.

Another approach to the determination of the health effects of occupational exposure to wastewater is to evaluate the causes of death of former employees in the wastewater treatment industry. This approach, known as a mortality study, has the advantage of potentially being able to measure the cumulative combined effect, if any, of all the conditions under which workers have labored during the course of their employment. Dean (8), reporting on a study by the University of Copenhagen, concluded that Copenhagen sewer workers were dying earlier than controls of comparable age; many of the sewer workers expired soon after retirement. The study also revealed that deaths due to cancer of the pancreas occured more often than expected, although a relatively small number of death certificates were examined.

The present study is an application of the mortality study approach to one of the largest wastewater treatment systems in the United States—the Metropolitan Sanitary District of Greater Chicago (MSDGC). Apart from its size and the corresponding large number of employees, MSDGC is appropriate for such a study because it has been in existence for more than a half century, and from its inception has operated its own retirement system—the Sanitary District Employees' and Trustees' Annuity and Benefit Fund.

The protocol for this study required that the workers included in the study had to have been employed by MSDGC at anytime during the years 1960 to 1969. A roster of all workers who have met the protocol has been compiled from records located in the MSDGC personnel office. Pensions records, where available, have been obtained and reviewed, and the vital status of each worker has been determined. Based on vital statistics tables for the United States, it is expected that there should be about 1075 decedents in the cohort by December 31, 1979. As of July, 1979, it has been determined that at least 704 members of this worker group have deceased; death certificates have been located for 510 of them. Of these, employment records have been located thus far for 402 employees. The data for this last group of workers have now been analyzed, and preliminary results have been produced.

For each of the 402 decedents, the underlying cause of death has been classified and coded by a qualified nosologist, according to the 8th Revision of the International Classification of Diseases (ICD) (9). For comparison, the distributions for age and cause of death among white males in the State of Illinois for each year from 1960 to 1975 have been abstracted from vital statistics tables of the United States. U.S. mortality data for the years 1976 to 1979 have not yet been published; therefore, it has been assumed that the distributions of deaths for these years are similar to those for 1975. From these data, the observed numbers of deaths and the expected numbers of deaths in five important cause-of-death groupings for the 402 decedents have been tabulated and are presented in Table 1. These cause-of-death groupings are neoplasms (ICD codes 140-209), heart disease (ICD codes 390-448), respiratory disease (ICD codes 470-493), accidents (ICD codes E800-949), and other causes. A chi-square statistic with four degrees of freedom, testing for significant difference between the observed and expected frequencies, was not significant (p = 0.20).

Table 1. Observed and Expected Numbers of Deaths (402 Workers)

Cause of death	Observed	Expected[a]
Neoplasms, all sites	90	78.1
Heart disease	227	238.6
Diseases of respiratory system	16	19.5
Accidents	9	13.9
All other causes	60	51.9

[a] For white males, State of Illinois, stratified by age and year of death (p = 0.20)

In an attempt to determine whether length of exposure might have an effect, the above data were subdivided according to years of employment with MSDGC, for those workers where this information was available. The chosen subdivisions for employment were 1 to 8 years, 9 to 16 years, and 17 or more years; the groups contained 64, 114, and 210 employees, respectively. The observed and expected numbers of deaths for the above five disease groupings are given in Tables 2 to 4 for the length-of-employment subdivisions. Chi-square statistics, each with four degrees of freedom, for the three length-of-employment subgroups resulted in p-values of 0.40, 0.26, and 0.65, respectively, and showed no outstanding differences between the numbers of observed and expected deaths.

Table 2. Number of Deaths: 1–8 Years of Employment (64 Workers)

Cause of death	Observed	Expected[a]
Neoplasms, all sites	16	12.8
Heart disease	32	35.2
Diseases of respiratory system	1	2.8
Accidents	2	3.4
All other causes	13	9.8

[a] For white males, State of Illinois, stratified by age and year of death (p = 0.40)

Table 3. Number of Deaths: 9–16 Years of Employment (114 Workers)

Cause of death	Observed	Expected[a]
Neoplasms, all sites	24	22.2
Heart disease	71	66.3
Diseases of respiratory system	2	5.4
Accidents	1	4.5
All other causes	16	15.6

[a] For white males, State of Illinois, stratified by age and year of death (p = 0.26)

Table 4. Number of Deaths: 17 or More Years Employment (210 Workers)

Cause of death	Observed	Expected[a]
Neoplasms, all sites	47	40.8
Heart disease	120	129.0
Diseases of respiratory system	11	10.6
Accidents	4	5.4
All other causes	28	24.2

[a] For white males, State of Illinois, stratified by age and year of death (p = 0.65)

To determine whether degree of exposure, as represented by type of employment of MSDGC, showed any mortality effects, Tables 5 to 12 were prepared. These tables represent a subdivision of the workers into four departments (Tables 5 to 8) and four job classification groups (Tables 9 to 12); each worker is classified into one of the four departments and into one of the four job class groups. The departments are research and development, engineering, maintenance and operations, and security and safety, with 35, 44, 286, and 21 workers, respectively. The job class groups are engineers and laboratory personnel, tradesmen, operating personnel, and laborers, with 55, 93, 122, and 85 workers, respectively. Observed and expected numbers of deaths and chi-square statistics with four degrees of freedom each were computed for these eight groupings and resulted in the following respective p-values: 0.35, 0.50, 0.35, 0.85, for the department groups, and 0.70, 0.60, 0.45, 0.60 for the jobs class groups. None of these are significant.

Table 5. Number of Deaths: Research and Development Employees (35 Workers)

Cause of death	Observed	Expected[a]
Neoplasms, all sites	9	7.0
Heart disease	23	20.6
Diseases of respiratory system	0	1.7
Accidents	0	1.0
All other causes	3	4.7

[a] For white males, State of Illinois, stratified by age and year of death (p = 0.35)

Table 6. Number of Deaths: Engineering Employees (44 Workers)

Cause of death	Observed	Expected[a]
Neoplasms, all sites	13	8.6
Heart disease	25	26.6
Diseases of respiratory system	1	2.2
Accidents	1	1.3
All other causes	4	5.3

[a] For white males, State of Illinois, stratified by age and year of death (p = 0.50)

Table 7. Number of Deaths: Maintenance and Operations (286 Workers)

Cause of death	Observed	Expected[a]
Neoplams, all sites	61	56
Heart disease	161	168.7
Diseases of respiratory system	11	13.8
Accidents	7	10.3
All other causes	46	37.2

[a] For white males, State of Illinois, stratified by age and year of death (p = 0.35)

Table 8. Number of Deaths: Security Guards, Safety, Etc. (21 Workers)

Cause of death	Observed	Expected[a]
Neoplasms, all sites	2	2.6
Heart disease	8	7.9
Diseases of respiratory system	0	0.7
Accidents	0	0.3
All other causes	11	11.7

[a] For white males, State of Illinois, stratified by age and year of death ($p = 0.85$)

Table 9. Number of Deaths: Engineers, Lab Staff, Etc. (55 Workers)

Cause of death	Observed	Expected[a]
Neoplasms, all sites	13	10.5
Heart disease	35	33.5
Diseases of respiratory system	2	2.7
Accidents	1	1.7
All other causes	4	6.6

[a] For white males, State of Illinois, stratified by age and year of death ($p = 0.70$)

Table 10. Number of Deaths Among Tradesmen (93 Workers)

Cause of death	Observed	Expected[a]
Neoplasms, all sites	24	18.1
Heart disease	51	55.5
Diseases of the respiratory system	5	4.6
Accidents	2	3.2
All other causes	11	11.7

[a] For white males, State of Illinois, stratified by age and year of death ($p = 0.60$)

Table 11. Number of Deaths: Operating Personnel (122 Workers)

Cause of death	Observed	Expected[a]
Neoplasms, all sites	23	24.3
Heart disease	67	71.8
Diseases of respiratory system	6	5.8
Accidents	3	4.1
All other causes	23	16.0

[a] For white males, State of Illinois, stratified by age and year of death ($p = 0.45$)

Table 12. Number of Deaths Among Laborers (85 Workers)

Cause of death	Observed	Expected[a]
Neoplasms, all sites	23	24.3
Heart disease	45	48.4
Diseases of respiratory system	1	4.0
Accidents	3	3.2
All other causes	13	11.1

[a] For white males, State of Illinois, stratified by age and year of death ($p = 0.60$)

The data was tabulated in Table 13 to compare with the finding reported by Dean (8) that Copenhagen sewer workers were dying early in retirement. Of the 402 decedents in our study, it was determined that 71 of them had retired from MSDGC. Of these 71, only 12 (17%) died within 12 months of their retirement date; this contrasts with Dean's report that 13 (41%) out of 32 died in the same calender year of their retirement in Copenhagen. This difference between the two studies in early death after retirement is significant at p = 0.019 by chi-square statistic with one degree of freedom.

Table 13. Number of Deaths in Early Retirement

Chicago, Illinois		
Within 12 months after retirement	12	(17%)
After 12 months of retirement	59	
Copenhagen, Denmark		
Within calendar year of retirement	13	(41%)
After calendar year of retirement	19	

(p = 0.019)

The final tabulation (Table 14) was made to determine if deaths due to cancer of the pancreas occurred more often than expected and to compare the results with the findings of Copenhagen study, which found that cancer of the pancreas did occur often. Our data did not show an excessive number of deaths due to cancer of the pancreas (p = 0.60).

In conclusion, in this preliminary study we did not find any outstanding frequency of deaths in the major subgroupings nor did we duplicate the results reported by Dean. However, it should be noted that the Copenhagen workers were exposed to the confined environments of sewers while those in the present study were engaged in the relatively more open environments of sewage treatment plants. Thus, the occupational exposures were not necessarily of the same type. The final report of this study will include additional comparisons and should involve more than twice as many death certificates as were available for this interim report.

Table 14. Number of Deaths Due to Pancreatic Cancer

Observed	6.0
Expected[a]	4.4

[a] For white males, State of Illinois, stratified by age and year of death (p = 0.60)

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Suppression of Aerosols at a Wastewater Treatment Plant

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ABSTRACT

The Metropolitan Sanitary District of Greater Chicago (MSDGC) is currently engaged in a program to evaluate aerosol suppression devices at its John E. Egan Wastewater Reclamation Plant. The conduct of this work by the MSDGC is in response to construction grant conditions imposed by the U.S. EPA following protracted litigation relative to the characteristics of aerosols to be emitted from the proposed O'Hare Water Reclamation Plant. Windborne aerosol particles are formed from the evaporation of droplets which are injected into the air by bubbles bursting at the air-water interface in wastewater aeration basins.

The techniques which may be used to suppress aerosols can focus on: 1) the droplets formed by the bursting bubbles or 2) the particulate residues which are left after droplet evaporation. Inertial impaction techniques may be applied to suppress the droplets formed; classical air cleaning techniques may be applied to the particulate nuclei.

The MSDGC has proposed an evaluation of several techniques of suppression, including: 1) bubble size reduction; 2) flat plates at the aeration tank surface; 3) partial covering of the aeration tank surface; 4) particle collection at the tank surface and removal by conventional scrubbers; 5) particle collection at the tank surface and removal by electrostatic precipitation; and 6) particle interception via a "green belt" or vegetative barrier. At this time only the vegetative barrier or "green belt" has been evaluated experimentally.

Preliminary results indicate that the rate at which microorganisms are aerosolized and emitted to the air from activated sludge aeration tanks is quite low and only a small proportion of these organisms are of the indicator type. Further, the total microorganism content of air immediately above the aeration tank liquid surfaces decreases exponentially with height at least within the first 100 cm above the aeration tank liquid surfaces, and the content appears to be influenced by factors such as the mixed liquor suspended solids concentration of the aeration tanks, bacterial die-off, fallback of larger particles, and dispersions by wind currents.

Although the scientific issues to be considered at this symposium may be of national and even international significance, it is at this particular time a question of special immediacy in the Chicago metropolitan area, where construction of the O'Hare Wastewater Reclamation Plant (OWRP) has just been completed and the facility is ready to be placed in operation.

The O'Hare plant, located just inside the south boundary of the city of Des Plaines, Illinois, is a facility with a treatment capacity of 75 mgd. It is designed to receive and treat the combined sewage and storm flows from a region known as the O'Hare or Upper Des Plaines Drainage Basin of northwestern Cook County, in the Chicago metropolitan area. Although the site is zoned industrial, the plant fence is just across Oakton Street from the homes of residents of the city of Des Plaines, a fact that has been the cause of a great deal of unhappiness and dismay on the part of some residents and officials of the city. Beginning in 1966, the city carried on a running battle in the state and federal courts for a period of 11 years in an effort to prevent the construction of the OWRP on the site where it is now located.

The Metropolitan Sanitary District of Greater Chicago (MSDGC), the regional agency that presided over the planning, design, and construction of the OWRP (with the aid of federal grant support), considered this project an essential segment of the pattern of facilities required to combat the mounting water pollution problems of the metropolitan Chicago region. It fought with all of its vigor to prevent the O'Hare project from being interrupted or sidetracked in the courts and to avoid or minimize as much as possible the costly delays occasioned by protracted litigation during a period of extreme inflation.

The battle was joined between the city and the MSDGC on a number of legal issues in the various lawsuits, but the central issue presented that is relevant to this symposium is whether the construction and operation of the OWRP at its present site would pose a health hazard to the residents of the city by virtue of microbes and viruses emitted into the atmosphere from the plant's aeration tanks.

Since the project would have an impact on the environment and federal funding was involved, an environmental assessment, full-scale public hearings, and Environmental Impact Statements (EIS's) were all required, under the provisions of the National Environmental Policy Act (1,2). Again, in the environmental assessment process, the question of whether there was a health hazard to the residents of the city from aerosols that would be emitted from the proposed plant became a central issue; and many pages of the final EIS's are devoted to this question. In the assessment process, with the city and the MSDGC in opposite positions, an intensive effort was made to gather such scientific evidence on the question as was available at that time and to present it both orally and in writing for inclusion in the EIS's.

The two-volume final EIS for the OWRP and solids pipeline was completed in May 1975, by the United States Environmental Protection Agency (U.S. EPA). A great many pages of the document are devoted to the inputs of the city and the MSDGC on the health hazard question and the analysis and conclusions reached by the EPA. As a part of the process, the EPA itself conducted an extensive literature survey to determine "the extent of the present knowledge on aerosol generation and its health implications."

The conclusion of the EPA, as it is stated on page 5-9, Volume I of the final EIS is as follows:

> *"It can be seen that there are innumerable factors which control the viability and infection potential of microorganisms commonly found in wastewater aerosols. To conclude that the presence of these aerosols will positively result in a public health hazard is not supported by scientific evidence. Since it is equally unsupportable to reach a conclusion that a potential health hazard does not exist for the residents in close proximity to Site 1, we find that in order to accomplish the intent and purpose of the National Environmental Policy Act mitigative measures are*

> *required to adequately suppress aerosol transmission from the aeration tanks. Should evidence become available that these additional facilities are not sufficient, we would require, and the MSDGC has indicated its willingness to implement, whatever additional mitigative remedies are necessary.*"

The litigation in the federal courts was concerned with resolving the questions raised by the contentions of the city that this conclusion by the EPA and the environmental assessment on which it was based were not legally adequate. This question was decided against the city in the U.S. district court and, on appeal, by the Seventh U.S. Circuit Court of Appeals.

In its opinion, the federal appellate court said (in relevant part):

> "*We believe it is clear from the material of record that EPA took the requisite hard look at this problem and reacted sensitively to it. EPA summarized in its analysis the data available (which was set out in full appendices) and stated its reasonable conclusion that no definitive answer could be made to the question of asserted health hazards from aeration. In response to the mere possibility that such hazards might be present in unregulated aeration, EPA took a conservative approach and required MSD to design, construct, and install devices to suppress aerosol emissions. The uncertainty regarding the very existence and scope of the potential health hazard is ignored by the City in its argument that the failure to specify standards and specific devices renders the pertinent EIS inadequate and in its insistence that the entire project be held in abeyance until definitive answers and solutions can be obtained. We believe the EIS unquestionably contains a fair statement of the problem and the solutions intended, insofar as was possible, and we do not believe more was required in this case. . . .*"

Meanwhile, as a part of the parade of litigation, the city filed an enforcement-type proceeding before the Illinois Pollution Control Board (IPCB), in which it contended essentially that, in issuing the permit for the construction of the OWRP, the Illinois Environmental Protection Agency was violating state law "by threatening the (city's) environment with air pollution in the form of odors, bacteria and viruses" that would be emitted by the plant when it was built.

The IPCB dismissed the city's complaint as "frivolous", and this ruling was affirmed, on appeal, by the Illinois appellate court.

In starting his opinion that the issue of a possible health hazard from aerosols from sewage treatment plants in this kind of context was not a proper subject for an enforcement proceeding before the board, Dr. Zeitlin of the IPCB said:

> "*Were there a concerned need to now control aerosols from sewage treatment plants, the proper forum would be the submittal of a proposed regulation to the Board considering the fact that the abatement of this possible emission would affect every sewerage treatment plant in the State of Illinois, whether they be existing, under construction, or proposed.*"

No rulemaking proceeding has yet been initiated before the IPCB to regulate aerosols emitted by sewage treatment plants.

The recommendations made in the final EIS as to the study of aerosols and mitigating measures resulted in corresponding grant conditions imposed by EPA in connection with the construction of the OWRP. The discussions we will be engaged in at this symposium will be concerned with some of the research data generated in fulfillment of those grant conditions and some of the resulting conclusions.

Specifically, this presentation will: 1) describe the aerosol suppression study currently being conducted by the MSDGC; 2) discuss the rationale behind the selection of the methods to be studied; 3) discuss the aerosol suppression methods to be studied; and 4) present some of the pertinent characterization data gathered thus far.

DESCRIPTION OF AEROSOL SUPPRESSION STUDY

The study involves physical, chemical, and biological characterization of various treatment streams and aerosols generated from the aeration tanks of the MSDGC's John Egan Water Reclamation Plant. In addition, methods to suppress the aerosols generated from a pilot plant simulating the Egan plant aeration tanks will be studied. The Egan plant was chosen for study since it very closely approximates the OWRP in sewage characteristics, method of sewage treatment, and physical configuration.

The study is broken down into three phases. These phases are separate and distinct entities, and each phase must be completed before the next phase is begun. Perhaps more important is the condition which requires that no phase of the project can be started unless shown to be warranted by conclusions reached on the basis of data gathered in a previous phase. A more comprehensive treatment of the experimental program and work plan is available (3).

The following sections describe the general procedures to be followed for sampling, sample analyses, and quality control during the course of the study.

Physical and Chemical Parameters

A number of physical and chemical measurements will be made on the raw wastewater, the wastewater influent to the aeration tanks, and the aeration tank mixed liquor of the first- and second-stage aeration tanks of the Egan plant. The Egan plant is a two-stage activated sludge plant. The first stage, which is designed principally for carbonaceous BOD removal operates at mixed-liquor suspended solids (MLSS) concentrations between 2,000 and 4,000 mg/l; the second stage, designed for biological nitrification, operates at MLSS concentrations between 1,000 and 2,000 mg/1. These physical and chemical measurements are listed in Table 1.

Biological Parameters

Biological characterization of wastewater samples and mixed liquor samples will consist of the biological parameters listed in Table 2.

Chemical Laboratory Quality Control

Prior to the start of the project, a series of distilled water standards will be prepared and submitted to the chemical laboratory for analysis. Five sets of duplicate samples of each parameter will be analyzed so that the precision and accuracy of each analysis will be determined.

In order to evaluate the daily performance of the chemical laboratory, quality control charts will be maintained for each chemical analysis. The procedure for constructing quality control charts as outlined in the U.S. EPA "Handbook of Analytical Quality Control in Water and Wastewater Laboratories" (1972) will be used.

In addition, monthly check samples will be prepared from certified standards and analyzed during the course of the experimental program.

Bacteriological Quality Control

Internal bacteriological quality control will be conducted along the lines of the following references:

- Environmental Protection Agency
  Bacteriological Survey for Water Laboratories
  EPA-103
- Handbook for Evaluating Water
  Bacteriological Laboratories
  EPA 67019-75-006
- Standard Methods for the Examination of Water and Wastewater 14th Ed.

Table 1. Physical and Chemical Parameters for Aerosol Study

1. Total solids (TS)
2. Total suspended solids (TSS)
3. Total volatile solids (TVS)
4. Chemical oxygen demand (COD)
5. Alkalinity
6. Nonionic detergent
7. Methylene blue active substances (MBAS)
8. Total dissolved solids
9. Ammonia (NH_4-N)
10. Total organic nitrogen (TON)
11. Orthophosphorus
12. Total phosphorus
13. Hardness
14. pH
15. Temperature
16. Dissolved oxygen (DO)
17. Chloride or other conservative indigenous ionic tracer
18. Viscosity
19. Surface tension
20. Bubble size
21. Bubble terminal velocity

Table 2. Biological Parameters for Aerosol Study

1. Total plate count (TPC)
2. Total coliform (TC)
3. Fecal coliform (FC)
4. Fecal streptococci (FS)
5. *Klebsiella pneumoniae*
6. *Salmonella*
7. *Pseudomonas aeruginosa*
8. Coliphage particles
9. Animal virus particle quantitation and, where specified, identification

Viral Analysis and Quality Control

Total viruses in raw sewage and mixed liquor will be analyzed by means of an $Al(OH)_3$, continuous-flow centrifuge technique (4). Basically, the procedure consists of adsorbing the indigenous viruses on an $Al(OH)_3$ precipitate, removing the precipitate from solution using a continuous-flow centrifuge, resuspending the precipitate, removing adsorbed viruses with sonification and Freon 113, and again separating the viruses by centrifugation. The virus-containing solutions will then be analyzed by plaque assay procedures using three cell cultures: 1) BGM (Buffalo Green Monkey) Kidney Cells; 2) WI-38 (Human Diploid Cell Strain); and 3) PMK (Primary Monkey) Kidney Cells. All plaques formed will be confirmed by repassage of the plaques in the same cell system. Only those plaques showing cytopathic effect on repassage will be registered as viruses in the virus assay. A representative selection of confirmed viruses will be identified by serum neutralization.

Quality control in the virus laboratory will include extensive log keeping, such as photographic records of the plaques formed in the first and second passage and a census of the types of plaques which develop and which are subsequently picked for repassage in the appropriate cell system. In addition, seeded quality control samples will be prepared and the seed viruses concentrated, isolated, and identified.

Quality Assurance Plan for Samplers

The air samplers employed in this project will be tested side by side for a sufficient number of runs to statistically examine the variation in collection efficiency among samplers. These runs will take place under a variety of experimental conditions to ensure that data is gathered for the wide range of operating conditions which will occur during the test program.

Since it is not possible to autoclave the high-volume samplers, it will be necessary to check periodically the sterilization procedures used by running sterile distilled water through them and analyzing for biological parameters 1 through 8 in Table 2.

For the times when the high-volume samplers are used for virus measurements, sterility checks will be made prior to all runs to ensure that no viruses are present.

Phase I

Phase I concentrates on defining the range of aerosol emissions that are produced by the Egan plant and the associated process conditions giving rise to these aerosol emissions. This is accomplished by measuring the physical, chemical, and biological properties of aerosols emanating from the aeration tanks of the Egan plant and relating these to measurements of the wastewater aeration process parameters and to environmental parameters which may have an influence on the aerosol properties. Work on Phase I is divided into six tasks as follows:

Task 1: A study of the diurnal and daily variation of the chemical and biological quality of raw wastewater, mixed liquor, and first-stage and second-stage aeration tank effluents of the Egan plant are to be conducted. Three 8-hour composite samples will be collected on each of 4 consecutive days for 2 weeks. Grab samples of mixed liquor will also be taken. All samples will be examined for physical and chemical parameters 1 through 3, 8 through 10, 12 and 14 (Table 1) and biological parameters 1 through 4, 6 and 7 (Table 2). Data pertaining to the physical, chemical, and biological parameters will be analyzed statistically so that subsequent wastewater sampling plans which depend upon the results of previous tasks can be adjusted accordingly.

Task 2: This task is designed to complete the characterization of wastewater and mixed liquor of the Egan plant which was begun in Task 1. However, this data, to be collected for a 30-day period, will include additional mixed liquor samples, and physical and chemical parameters 1 through 21 (Table 1) and biological parameters 1 through 8 (Table 2). In addition, on 6 days, samples of raw wastewater, first-stage effluent, and mixed liquor from both aeration stages will be collected and analyzed for animal viruses. The entire sampling program will be established according to the results obtained in Task 1 to ensure that samples are representative of the daily and diurnal variations.

Task 3: The purpose of this task is to estimate the range and variation of the rate of emission, particle size distribution, and biological content of aerosols emitted from point to point over the surface of the aeration tanks of the Egan plant and to relate the aerosol properties observed with the associated characteristics of mixed liquor.

On each of 15 days on which wastewater and mixed liquor are to be collected during the period of Task 2, the aerosols present directly above the aeration tank surface will be sampled with tyndallometers at eight samping stations on each stage of the Egan plant. The aerosol concentration and size distribution will be obtained.

On each of 5 days on which the tyndallometer measurements are made, the biological properties of the aerosols will be determined with Andersen six-stage and AGI samplers at three sampling sites on each stage. These sites will be determined on the basis of previous tyndallometer measurements. Andersen samples will be examined for biological parameters 1 through 7 (Table 2), and AGI samples will be analyzed for biological parameters 1 through 8 (Table 2).

Task 4: It is possible that aeration tank mixed-liquor solids concentrations may have a significant influence on aerosol emission rates. Therefore, tests will be conducted in a 15 ft deep column fitted with a diffuser plate having a structure and porosity identical to the diffuser plates of the OWRP and Egan plant. Mixed liquor will be withdrawn from the Egan aeration tanks and diluted or concentrated to MLSS levels of 2,000 to 4,000 mg/1. Aeration rates will be adjusted to DO levels of 1 to 5 mg/1 for first-stage mixed liquor, and 2 to 6 mg/1 for second-stage mixed liquor. A tyndallometer will be used to examine the concentration and particle size distribution of aerosols emitted with various conditions of MLSS levels and aeration rates.

Task 5: The purpose of this task is to ascertain whether animal viruses are present in the Egan aeration tanks and whether viruses may be detected as constituents in aerosols emitted from these tanks. A total of 10 high-volume samplers will be placed downwind of the Egan tanks, but as close as possible to the edge of these tanks. Sampling times will be on the order of 6 to 8 hours. The sampling fluid of all 10 samplers will be pooled for analysis and examined for animal virus content. One upwind sample will act as a control.

In addition, a composite mixed liquor sample will be collected during each aerosol sampling run. This sample will be a composite of samples gathered in the inlet, outlet, and midpoint of each aeration tank and will be analyzed for chemical parameters 1 through 21 (Table 1), and biological parameter 9 (Table 2), animal virus.

Task 6: The purpose of this task is to establish the magnitude of the site-specific factors for the application of a selected dispersion model to be used in subsequent tasks of the study and to verify that the results are consistent with experiences and applications of this model under similar circumstances. A total of 30 aerosol sampling runs will be conducted. During each aerosol sampling run, one aerosol station will be established upwind of the aeration tanks of the Egan plant and six stations downwind at distances of 5 to 50 m. During each run, a high-volume sampler and a six-stage Andersen sampler will be operated at elevations of 5 and 10 m above the ground. During each run, tyndallometer measurements will be performed at each ground level sampling station. Sampling fluid will be analyzed for biological parameters 1 through 8 (Table 2). The Andersen plates will be analyzed for the biological parameters 1 through 7 (Table 2).

During each sampling run, a composite mixed liquor sample will be collected at the inlet, outlet, and midpoint of each aeration tank. These samples will be analyzed for physical and chemical parameters 1 through 21 (Table 1) and biological parameters 1 through 8 (Table 2).

Report—Phase I: The complete results of the work under Phase I will be compiled into a report for review by MSDGC consultants and the U.S. EPA. Phase II will not proceed until the report has been fully reviewed and final direction for further work has been decided.

Phase II

Phase II will begin with the construction of a pilot facility representing a 25 ft cross section of one channel of a standard aeration basin of the OWRP. The pilot plant will be used to conduct a full-scale test of aerosol suppression devices. The pilot plant aeration tank is designed to generate an aerosol particulate with physical and biological characteristics similar to those actually emitted by the Egan and O'Hare plants. Mixed liquor from the Egan plant will be fed to the pilot plant at detention times similar to those in a 25 ft cross section of the tanks and then returned back to the Egan plant.

The pilot plant will be equipped with five different aerosol suppression devices which will be described in another section of this report.

Phase II will be conducted to determine whether the aerosol emissions of the pilot plant are representative of the aerosol emissions from the Egan plant. A total of 20 aerosol sampling runs will be performed. During these runs, samples of the aerosol emissions of the pilot plant and the Egan plant will be collected simultaneously. Aerosol sampling runs will be scheduled to obtain measurements under varied environmental conditions. Samples will be collected at ground level at one upwind and six downwind locations of the Egan aeration tanks, and at three locations immediately upwind over center and downwind of the pilot plant. In each run, Andersen six-stage and high-volume samplers will be employed along with tyndallometer measurements. In addition, Andersen six-stage and AGI samples will be collected at an elevation of 5 m above ground immediately downwind of the Egan plant and the pilot plant. During each run, composite mixed liquor samples will be collected from the Egan plant and pilot plant. Sample collection fluid from the high-volume samplers will be analyzed for biological parameters 1 through 8 (Table 1), while the Andersen samples will be analyzed for biological parameters 1 through 7 (Table 2). Each mixed liquor sample will be analyzed for chemical parameters selected on the basis of data from Phase I and for biological parameters 1 through 8 (Table 2).

Report—Phase II: The findings of Phase II will be compiled into an interim report. Again, this report will be reviewed by the U.S. EPA and MSDGC consultants. Phase III, with the exception of the vegetative barrier study, will not begin until a final determination is made as to the direction to be taken based upon the conclusions and recommendations of this report.

Phase III

In this phase, the five aerosol suppression devices are to be tested on the pilot facility. In addition, a study was included to determine the efficiency of a vegetative barrier as an aerosol suppression device. This vegetative barrier study was conducted on a laboratory scale using a wind tunnel, and has been completed.

Pilot Plant Tests: Each of the five aerosol suppression devices will be evaluated by operating trials utilizing the pilot plant. A total of 15 complete performance trials of each system will be performed. The operating mode of the pilot plant is to be selected based upon data collected in Phase II. Each performance trial will consist of two sampling runs: one in which the aerosol emisisions of the pilot plant will be sampled without the operation of the suppression technique, and the other during the operation of the suppression device being tested. During each run, aerosol samples will be collected at one upwind station and six downwind ground level stations at distances of 5 to 50 m from the pilot plant. A high-volume and an Andersen six-stage sampler will be used at each station. One Andersen six-stage sampler will also be located at an elevation of 5 m above ground at five downwind locations. Tyndallometer readings will be taken at each station during a run. A composite mixed-liquor sample of the pilot plant will be gathered for each run.

Sample collection fluid of the high-volume samplers will be analyzed for biological parameters 1, 3, and 8 (Table 2). Andersen samples will be examined for biological parameters 1 and 3 (Table 2).

Mixed liquor samples will be examined to determine physical and chemical parameters 1 through 4, 6 through 8, and 17 (Table 1) and biological parameters 1, 3, and 8 (Table 2).

Report—Phase III: At the completion of Phase III, the District will prepare a complete draft final report of the project. Recommendations will be presented regarding the method or combination of methods concluded to be the most effective and reliable, considering estimated capital and operating costs, for suppression of aerosol emissions of aeration facilities at the OWRP, with related proposed detailed design criteria. The report will review the facilities and methods employed, review all experimental and test data, perform analyses of data and results, and conduct a full comparison and discussion of the performance, reliability, and estimated costs of each alternative aerosol suppression technique examined during the project.

Aerosolization Process

The typical process whereby aerosols are generated in a wastewater treatment plant aeration tank can be characterized as follows (Figure 1) (5,6,7,8):

1. A 600μm diameter bubble rises to the surface of the aeration tank.
2. The bubble bursts and ejects about 5 droplets of 60μm diameter.
3. The droplets rise to a height of about 8 cm above the surface.
4. The droplets evaporate to form windborne aerosol particles.

These windborne aerosol particles exhibit equivalent diameters of about 12 μm microscopically and 6 μm aerodynamically, as characterized by the Andersen six-stage sampler. Based on the above particle characteristics, it can be inferred that the particles are very flocculent and have a low bulk density of about 0.25 g/cm³.

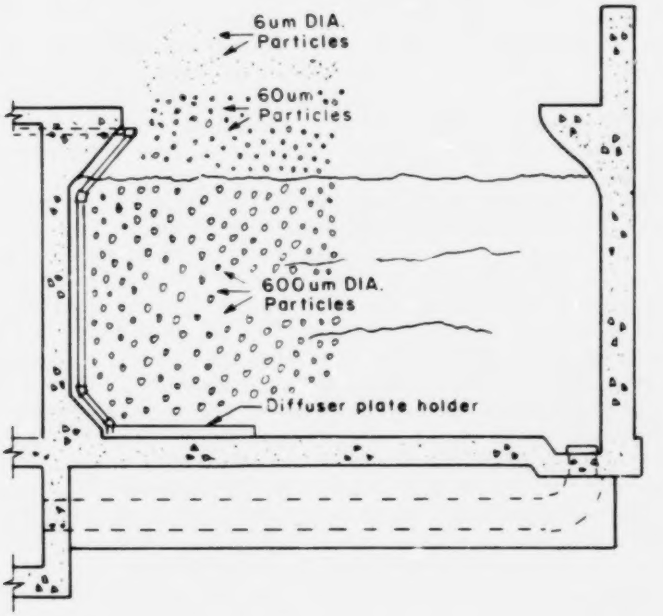


Figure 1. Section of Aeration Tank Showing Formation of Droplets and Airborne Particles

Rationale for Methodologies and Techniques

The methodologies or techniques which may be considered for suppression of aerosols from wastewater aeration tanks are as follows:

- suppression of the droplets which are ejected from the surface of the wastewater by the bursting bubbles
- suppression or capture of the solid particle residues left after evaporation of the droplets

Suppression of the droplets would best be accomplished by inertial impaction devices whereas collection of the solid particulate residues would be more amenable to classical air cleaning principles other than inertial impaction.

DEVICES FOR SUPPRESSING AEROSOLS

Devices Considered

Many devices or alternations in the treatment process have been proposed for the suppression of aerosols from wastewater treatment plants. A listing of these is presented here to indicate the difficulty involved in the task of choosing an appropriate suppression system (Table 3).

At-the-Surface Suppression: Not all of the methods proposed would necessarily have the same probability of success. For example, Woodcock and others (6,7) have shown that ejected droplets are about one-tenth the diameter of the bubble from which they originate. Thus, it should be possible, theoretically, to reduce the bubble sizes to such an extent that the resulting droplets and particles would be too small to carry any microorganisms. Reduction in bubble size, while attractive in its simplicity, is not a practical approach to aerosol suppression. In theory, it should be possible to produce oxygen bubbles so small that they would dissolve completely before reaching the surface. Such bubbles actually pick up other dissolved gases during their travel, however, and do not disappear.

Of the various types of floating covers which have been proposed for droplet suppression, all have drawbacks which eliminate them as useful candidate systems for actual testing. The expense of tall oil and its potential for degrading effluent quality, and the foaming characteristics of detergents eliminate them from consideration. Expanded plastic foam such as polyurethane could be made to float on the surface and represents a better candidate than either tall oil or detergents. The plugging of the polyurethane matrix, however, would necessitate frequent replacement as the material would not be cleanable. The use of ping-pong balls as a floating cover to suppress droplet emission is intuitively attractive because of its simplicity. Such a cover would be self-cleaning, and long-lasting, although less efficient than a polyurethane foam float. Unfortunately, ping-pong balls tend to travel with the flow and pile up at the end of the channel; they do not stay evenly distributed over the surface.

Above-the-Surface Suppression: Above-the-surface methods for droplet suppression would appear to have the greatest probability of success, although a number of methods proposed have serious limitations. Multiple-layer or knitted mesh screens would probably be more efficient than single-layer screens, but would be more difficult to clean. Fiber bed filters, while theoretically very efficient, would plug up due to accumulation of solids. Polyurethane foam used as a filter would again be subject to plugging and require frequent replacement. The use of overlapping flat plates (such as those found in awnings) appears to be a good candidate for inertial impaction of the droplets as does the use of properly spaced spray nozzles. The use of a high-speed rotating brush to capture droplets before evaporation, while imaginative, is not very practical.

Table 3. Suppression Devices Considered

- Droplet suppression techniques
  - At-the-surface methods
    - Bubble size reduction - smaller plate size; not practical
    - Floating covers
      - Oil - surface tension reduction - tall oil
      - Collapsing foam - detergent
      - Permanent foam - polyurethane sheets
      - Ping-pong balls - floating on surface
  - Above-the-surface methods
    - Single layer screen - 100-200 mesh
    - Multiple layer or knitted mesh screen
    - Fiber beds
    - Foam or granular bed
    - Flat plate
    - Water spray
    - Rotating brush
- Evaporated particle suppression by collection
  - At-the-canopy
    - Sedimentation
    - Multiple cyclone
    - Scrubber
    - Electrostatic precipitator
    - Fabric filtration
  - Downwind of the tank - vegetative barrier

Suppression by Collection: Under a canopy placed over the area where the bubbles burst, sedimentation could be an effective suppression mechanism. Due to the slow rise velocity of the air under the canopy, many of the particles would settle back into the water. A multiple-cyclone could collect particles under the canopy; however, due to their flocculent nature, they might be crushed into smaller particles and reentrained. A low-energy scrubber attached to the exhaust stream from the canopy would have a good probability of success as would the use of an electrostatic precipitator. Fabric filtration (bag filters) would have a very high collection efficiency, and be relatively uncomplicated; however, the size requirements for such an installation at already crowded facilities might preclude their use.

The only method proposed to intercept particles downwind of the tank is a "green belt" or vegetative barrier. Thus far, this is the only method which has been examined experimentally. The results of these experiments are presented elsewhere in these proceedings under the title "Effectiveness of Aerosol Suppression by Vegetative Barriers" (J.C. Spendlove).

From the preceding discussion, it is obvious that although many methods were proposed, only a few methods were worth serious consideration. A total of five (excluding the vegetative barrier) techniques were chosen for further consideration from among all of those proposed. Included in the list were two inertial impaction techniques, two under-the-canopy techniques, and one disinfection device which was not considered under the physical methods proposed.

Devices Chosen for Complete Testing

The following is a list of the devices which the MSDGC has chosen for further testing along with a brief description of each (Table 4).

Inertial Impaction Devices:

- *Slats over the tank* (Figure 2)
  The system consists of two layers of overlapping slats suspended over the entire aeration tank surface. Each slat should be 4 to 8 in wide. The lower layer should be no more than 4 to 6 in above the surface of the water, the closer the better, with the upper layer 1 in above the lower layer. The slats may be corrugated for support.
- *Water spray* (Figure 3)
  This system should consist of a sprinkler system with spray nozzles designed to produce water droplets of from 50 to 300 μm diameter. The nozzles are positioned so that the resulting spray completely covers the tank 12 in above the surface.

Particle Suppression or Collection Devices:

- *Parabolic cover over diffuser plate area* (Figure 4)
  The system consists of a fiberglass or metal canopy extending 8 ft over the aeration tank surface to cover the diffuser plate area. Both edges of the cover are submerged. The top of the cover should be 2 to 4 ft above the surface of the water at its highest point. There is an exhaust manifold along the entire length, venting into a single discharge point.
- *Parabolic cover with electrostatic precipitator* (Figure 5)
  This system is identical to the parabolic cover system described above (Figure 4), with the addition of an appropriately sized electrostatic precipitator mounted on the discharge side of the canopy exhaust vent.
- *Ultraviolet lights* (Figure 6)
  This system should consist of approximately 56 30-watt UV lamps arranged in four rows over each aeration tank. Each lamp is 36 in long with reflectorized fixtures and is suspended 3 ft above the surface of the water. Each fixture should contain two lamps and be wired so that either or both lamps can be operated.

The MSDGC proposes to test each of these devices on a pilot plant which represents a full-scale cut through one of the aeration tanks. Design criteria for construction can be developed from the results of these tests, should this be necessary.

Table 4. Suppression Devices Chosen For Complete Testing

- Inertial impaction devices
  - Slats over the tank
  - Water spray
- Particle suppression or collection devices
  - Parabolic cover over diffuser plate area
  - Parabolic cover with electrostatic precipitator
  - Ultraviolet lights

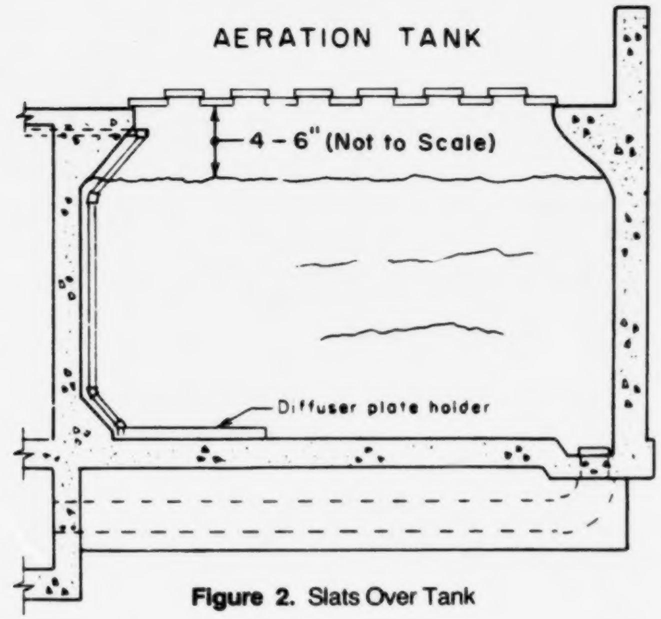

AERATION TANK
4 – 6" (Not to Scale)
Diffuser plate holder

Figure 2. Slats Over Tank

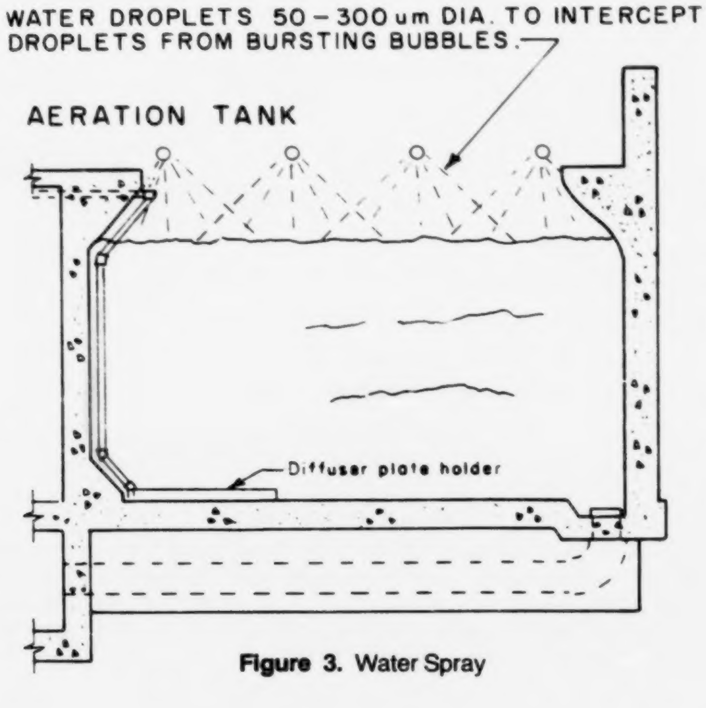
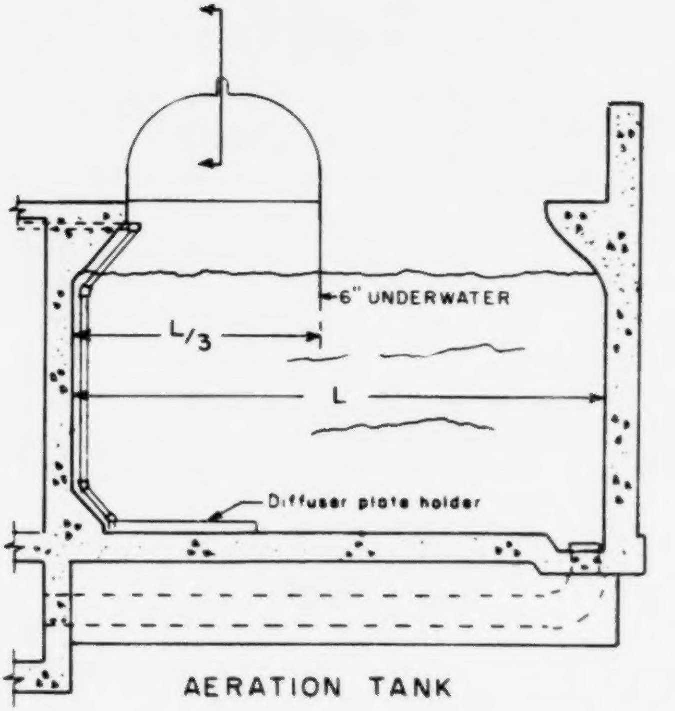
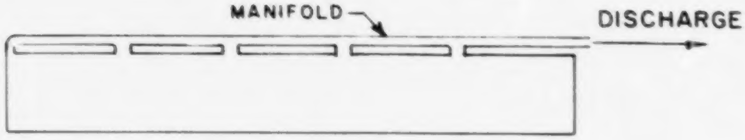

WATER DROPLETS 50 – 300 um DIA. TO INTERCEPT DROPLETS FROM BURSTING BUBBLES.
AERATION TANK
Diffuser plate holder

Figure 3. Water Spray


6" UNDERWATER
L/3
L
Diffuser plate holder

AERATION TANK


MANIFOLD
DISCHARGE

SECTION AS SHOWN ABOVE

Figure 4. Parabolic Cover

Preliminary Results

The primary goal of Phase I of the aerosol study is to characterize the existing aerosol emissions from the aeration tanks at the Egan plant with the main emphasis on microbial emissions. A number of sampling runs have been conducted directly over the aeration tanks in order to define the source strength emission rate of aerosols.

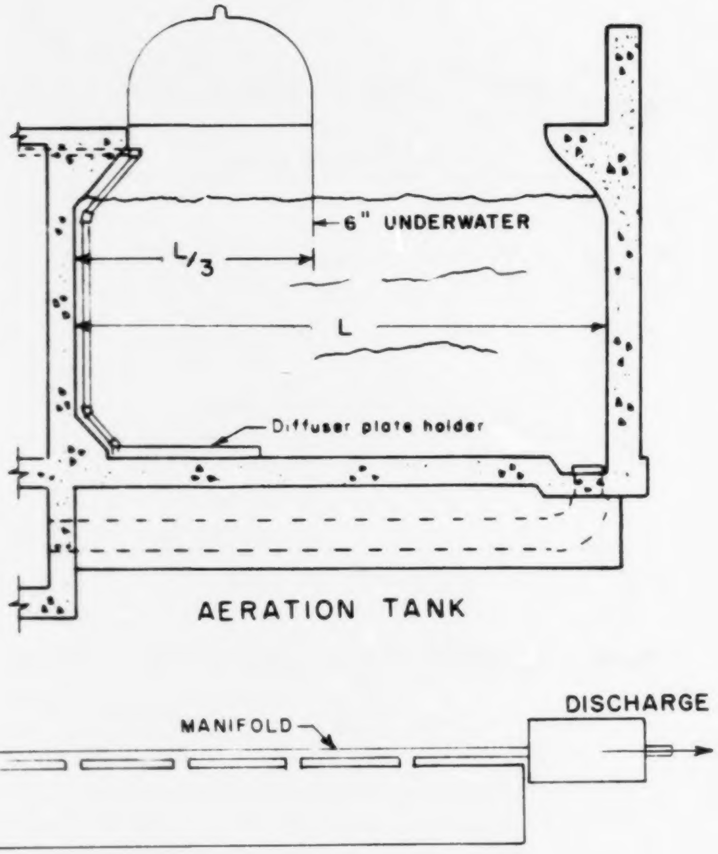


Figure 5. Parabolic Cover with Electrostatic Precipitator at Discharge

Figure 7 presents the results of one such sampling run. Samples were collected with Andersen six-stage viable samplers positioned at ground level 0.3 meters over the liquid surface of the first-stage aeration tanks at a number of locations along the length of the tank. A total plate count analysis was performed on all samples collected. As can be seen, total plate count concentrations ranged from 866 to 1420 colonies/m^3 air over the tanks. A sample collected at the same time 15 m upwind of the tanks showed 284 colonies/m^3 air.

Figure 8 presents similar data collected above the second-stage aeration tanks. One difference, though, is that these samples were collected at a height of 2.4 m above the liquid surface. This height was chosen for this sampling run because the liquid level of the second-stage aeration

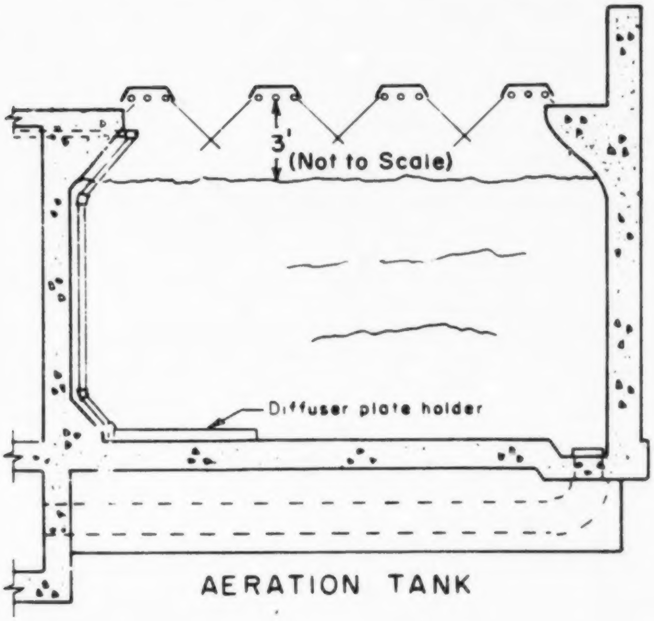
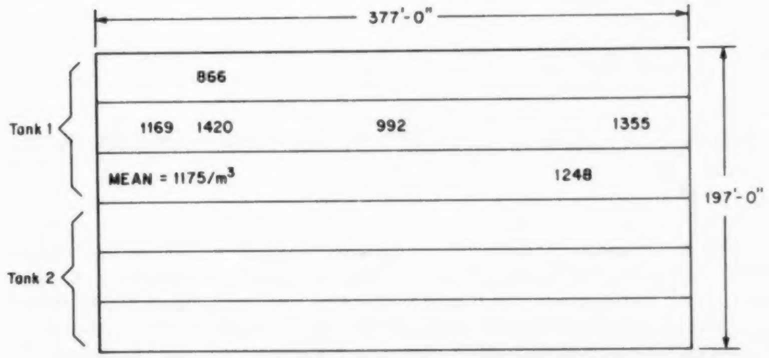

3'
(Not to Scale)
Diffuser plate holder
AERATION TANK

Figure 6. Ultraviolet Light (Disinfection of Airborne Particles)

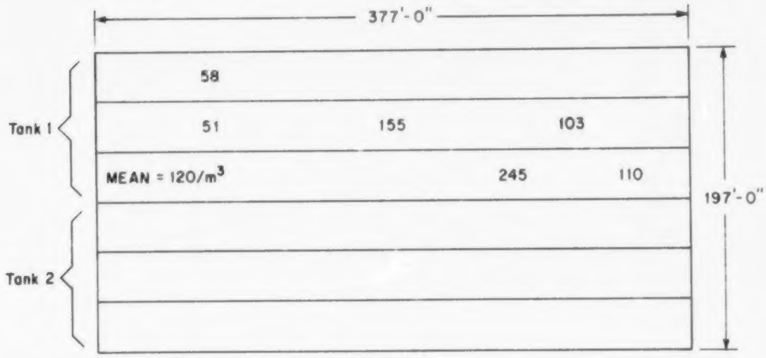
THE METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO


377'-0"
197'-0"
866
Tank 1
1169
1420
992
1355
MEAN = 1175/m³
1248
Tank 2

UPWIND BACKGROUND = 284 (SAMPLES COLLECTED 15 METERS FROM TANKS)
NOTE: ALL SAMPLES COLLECTED 0.3 METERS ABOVE WATER SURFACE
WITH ANDERSEN 6-STAGE VIABLE SAMPLERS.

Figure 7. Bacterial Concentration in Air Above Stage 1 Aeration Tanks (All values expressed as colonies/m^3 air)

THE METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO



UPWIND BACKGROUND = 89 (SAMPLES COLLECTED 15 METERS FROM TANKS)
NOTE: ALL SAMPLES COLLECTED 2.4 METERS ABOVE WATER SURFACE
WITH ANDERSEN 6-STAGE VIABLE SAMPLERS.

Figure 8. Bacterial Concentration in Air Above Stage 2 Aeration Tanks (All values expressed as colonies/m^3 air)

tanks is actually 2.4 m below ground level in order to allow for gravity flow of wastewater through the treatment plant. Thus, the sample was actually taken at ground level. As can be seen, the total count concentration ranged from 51 to 245 colonies/m^3 air at 2.4 m above the liquid surface. Although the data shown in Figure 8 were not collected on the same day as those shown in Figure 7, there appears to be a significant decrease in the bacterial concentration at this slightly increased height above the liquid surface.

These findings led to the decision to conduct another set of experiments in which the effect of height above the liquid surface was examined more closely. Andersen six-stage viable samplers were positioned approximately 7, 12, 32, 48, 73, and 99 cm above the liquid surface of the aeration tanks and operated simultaneously.

Figures 9 and 10 present the results of these sampling runs above the first stage and second-stage aeration tanks, respectively. These figures indicate that there is an exponential decrease in the bacterial concentrations in air within the first 100 cm above the liquid surface. Counts decreased from 1766 colonies/m^3 air to 462 colonies/m^3 air over the first-stage and from 769 colonies/m^3 to 189 colonies/m^3 over the second-stage. This decrease in concentration is probably due to a number of factors, including bacterial die-off, fallback of larger particles, and dispersion by wind currents.

The data presented thus far have dealt with total plate counts collected with the Andersen six-stage viable samplers. On a limited number of days, comprehensive bacterial analyses have been done on the Andersen sampler plates in order to study the occurrence of indicator organisms in the air. The results of the most comprehensive run thus far

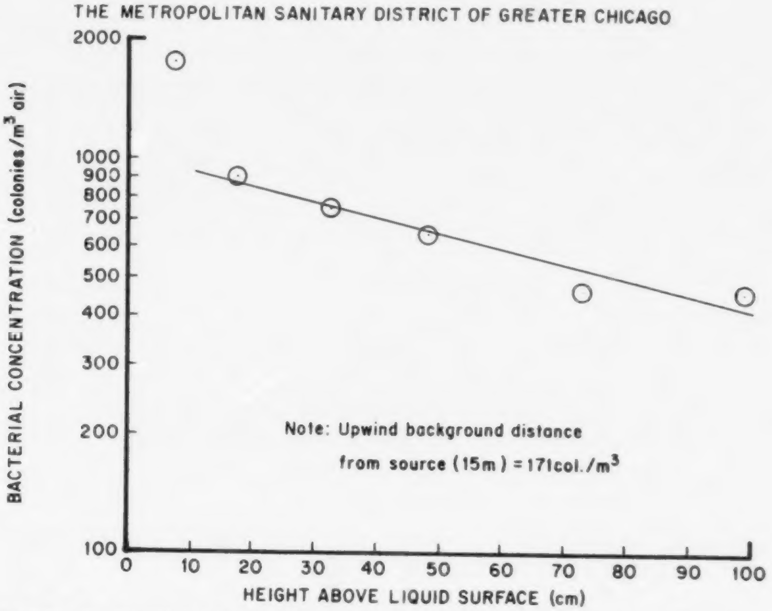


Figure 9. Bacterial Concentration in Air Versus Height Above Liquid Surface in Stage 1 Aeration Tanks (Samples collected with Andersen six-stage viable samplers)

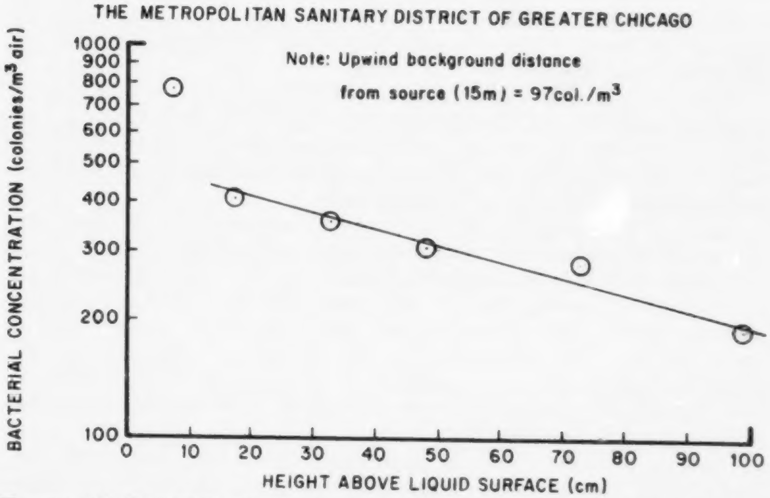


Figure 10. Bacterial Concentration in Air Versus Height Above Liquid Surface in Stage 2 Aeration Tanks (Samples collected with Andersen six-stage viable samplers)

are presented in Table 5. This table compares the bacterial counts in an air sample collected directly above the first stage aeration tanks with those collected 10 m upwind of the tanks with respect to both indicator organism content, and their distribution within each stage of the Andersen sampler. Six indicator organisms were examined in addition to total plate count. The most important points to note are that: 1) although the total plate count above the aeration tank was 551 colonies/m³ air, the combined count of all the indicator organisms was only 30 colonies/m³ air, or roughly 5% of the total; and 2) while the background air samples were taken only 10 m upwind from the aeration tanks, they were negative for indicator organisms.

Table 5. Comparison of Bacterial Concentrations in Air 0.3m Above Stage 1 Aeration Tanks and Upwind Background

	Colonies/m³ air for each Andersen sampler stage						
Organism[a]	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Total
TPC	157 (90)[b]	114 (46)[b]	118 (37)[b]	75 (54)[b]	67 (54)[b]	20 (39)[b]	551(320)[b]
TC	2 (0)	2 (0)	1 (0)	2 (0)	1 (0)	1(0)	9 (0)
FC	2 (0)	0 (0)	2 (0)	1 (0)	1 (0)	2 (0)	8 (0)
FS	0 (0)	2 (0)	0 (0)	1 (0)	4 (0)	0 (0)	7 (0)
K	2 (0)	0 (0)	0 (0)	2 (0)	1 (0)	0 (0)	5 (0)
S	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
P	0 (0)	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	1 (0)

[a]TCP = total plate count; TC = total coliform; FC = fecal coliform; FS = fecal streptococci; K = *Klebsiella pneumoniae*; S = *Salmonella*; P = *Pseudomonas aeruginosa*
[b]Background values (in parentheses) determined 10 m upwind from tanks

In order to gain a further perspective on the low rate of bacterial emissions actually emanating from the aeration tanks, the data in Table 6 is presented. This table shows the bacterial concentrations measured in the first stage mixed liquor at the Egan plant at the same time that the air sample data presented in Table 5 was collected. As can be seen, bacterial concentrations in the mixed liquor as expressed by total plate count are in the range of 10⁸ counts/100 ml of mixed liquor. The most prevalent indicator organisms, such as fecal coliform and fecal strepto-

Table 6. Bacterial Concentrations in Stage 1 Aeration Tank Mixed Liquor at the John Egan Water Reclamation Plant

	Counts/100 ml[a]							
Station	TPC	TC	FC	FS	K	S	P	CPH
Influent	5.8×10^8	1.3×10^8	1.5×10^4	4.7×10^6	0/4[b]	2.2×10^1	2.8×10^4	3.3×10^1
Midpoint	6.2×10^8	4.6×10^7	2.4×10^4	3.9×10^6	1/4[b]	4.6×10^1	2.2×10^4	$<3.0 \times 10^1$
Effluent	9.1×10^8	3.4×10^7	1.3×10^4	6.0×10^6	2/4[b]	1.2×10^1	4.6×10^4	7.0×10^1

[a]TPC = total plate count; TC = total coliform; FC = fecal coliform; FS = fecal streptococci; K = *Klebsiella pneumoniae*; S = *Salmonella*; P = *Pseudomonas aeruginosa*; CPH = coliphage particles
[b]0 Confirmed out of 4 colonies picked

cocci in the aeration tank mixed liquor, are in the 10^6 counts/100 ml range. Thus, the data in Table 5 indicate that the rate at which microorganisms are aerosolized and emitted to the air from the aeration tanks is indeed very low.

CONCLUSIONS ON PRELIMINARY RESULTS

Although the results presented here are preliminary with respect to the total work load for all three phases, they are, however, relevant to, and consistent with, the prinicipal mission of Phase I, which is designed to:

> *"Measure the physical, chemical and biological properties of aerosols emanating from the aeration tanks of the Egan WRP and relate these to measurements of the wastewater aeration process parameters of the plant, and environmental parameters which may have an influence on the aerosol properties. . . . the performance characteristics of the Egan WRP being presumed to be representative of the planned operation of the O'Hare WRP."*

Based on the data herein presented, the following conclusions are made:

- The rate at which microorganisms are aerosolized and emitted to the air from activated sludge aeration tanks is quite low, and only a small proportion of these organisms are of the indicator type.
- The concentration of total background microorganisms is highly variable and range from about 100 to 300 colonies/m^3 air for distances up to 15 m upwind from the aeration tanks.
- The total microorganism content of air immediately over the aeration tank liquid surfaces:
  1. decreases exponentially with height at least within the first 100 cm above the aeration tank liquid surface
  2. approaches background concentrations by extrapolation of current data within 2.5 to 4 m above the aeration tank liquid surface
  3. appears to be influenced by several factors, including the mixed-liquor suspended solids concentration of the aeration tanks, bacterial die-off, fallback of larger particles, and dispersion by wind currents.

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DISCUSSION

MR. SCHWARTZ: I have read that one of the common occurrences at activated sludge treatment plants is that operators will sometimes overaerate their wastes. I wonder if it would be possible to conduct a study showing that you can diffuse at a minimum rate and cut down on the amount of bursting bubbles that occur?

DR. LUE-HING: My answer to your question is we are interested in reducing air usage because by reducing air usage, we reduce costs. The costs of energy today is such that we can't ignore any procedure that will cut our costs down. In fact, within the R & D Department we are currently conducting a study aimed at maintaining effective wastewater treatment at reduced aeration rates, but not because of aerosols; it costs too much to pump air through sewage. We are about halfway through this study, and we are coming up with some recommendations which tell us that we can use less air. Our reasoning for this is not aerosol; it is just plain money.

MR. SCHWARTZ: In the event that you go through with studying ultraviolet light as a suppression method, do you have a maintenance technique for keeping the light screened so as not to be covered with particulate matter?

DR. LUE-HING: I am glad you asked that because we have about 5 or 6 years of experience with ultraviolet lamps on a much less hostile situation, using microscreens, where we don't have the splashing. We eventually got rid of them because we couldn't maintain them, and they were just a few 6 ft lamps. We are now talking perhaps about 3000 ft lamps per tank. However, we plan to take a look at it if we get that far.

Effectiveness of Aerosol Suppression by Vegetative Barriers

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The Metropolitan Sanitary District of Greater Chicago, Illinois

ABSTRACT

Concern about potential public health hazards of microbial aerosols emanating from wastewater treatment aeration tanks prompted the U.S. Environmental Protection Agency to ask the Metropolitan Sanitary District of Greater Chicago to characterize aerosol emissions and investigate ways to suppress them. One technique studied to date for suppressing these aerosols involves reduction by filtration or aerosol dispersion and dilution, based on the densities of coniferous and deciduous vegetation planted around treatment basins. The extent of filtration as a function of vegetation density and wind speed was studied in a low-speed wind tunnel. Filtration effectiveness was determined by reduction in aerosol concentrations of *Bacillus subtilis* var. *niger*, disseminated as particles of similar size to those emitted from treatment plants. Data collected experimentally were combined with those values reported in the literature for vertical mixing and dilution created by barriers. Results indicated that the maximum reduction possible in aerosol concentration and mass median diameter (MMD) of particles by filtration was 50% when type and density of the barrier together with wind speed were considered. By contrast, the literature suggested that dispersion rather than filtration would be the principal mechanism involved for vegetative barriers in suppressing aerosols by orders of magnitude. Our results indicate that strategically placed vegetation should effectively suppress aerosols emanating from wastewater treatment facilities.

Aeration basins of wastewater treatment facilities may serve as source of statistically significant concentrations of microbial aerosols. These aerosols are primarily generated through the bubble-breaking mechanism described by Blanchard and Syzdek (1). Their production is caused by the extensive use of aerators. Aerosols thus produced contain viable microorganisms, some of which are potential pathogens.

Microbial aerosols emitted from sewage treatment plants have been studied by several investigators (2-6). Kenline and Scarpino (5) found particles of these aerosols to be in a size range of 1 to 20 μm in diameter. It has been shown by Parker et al. (7), that the viability of such airborne microorganisms may be sufficient to allow their transport several kilometers downwind of wastewater treatment facilities.

A variety of means by which such aerosols might be suppressed have been proposed and some are under consideration as part of a U.S. EPA-funded study by the Metropolitan Sanitary District of Greater Chicago. Examples include: 1) thin metal strips mounted in layers over the aeration surface; 2) deflector covers over the diffuser area; 3) water spray to intercept droplets; and others. Another alternative involving relatively economical implementation and maintenance, entails planting a vegetative barrier of trees and shrubs around the aeration basins. In addition to the increased mixing and dilution of aerosol resulting from deformation of air streamlines at the vegetative barrier, it was expected that some filtration would occur as the aerosols passed through the vegetation. If aerosol suppression of vegetation were effective, these barriers could be strategically placed around wastewater treatment facilities to provide aerosol reduction through a combination of mixing/dilution, and filtration.

The purpose of this study, then, was to examine the aerosol filtering capacity, as a function of wind speed, among various densities of both coniferous and deciduous vegetation and to conduct a survey of the literature on the effects of such a barrier on vertical mixing and dilution of aerosol. It was felt that from the experimental data and the surveyed dilution effects, an overall aerosol suppression effect of vegetative barriers could be synthesized.

Experimental Methods

The experimental portion of this study was performed in a low-speed wind tunnel, the Atmospheric Simulation Facility (ASF), located at Calspan Corp., Buffalo, New York. A photograph and schematic drawing of the ASF are shown in Figure 1. The facility is 24 m long, 1.8 m high, and 2.4 m wide. A large fan at one end of the ASF draws air through the tunnel. The facility was initially designed, and is primarily used, for scale tests of atmospheric turbulence and diffusion.

Aerosols of *Bacillus subtilis* var. *niger*(BG), a common tracer organism, were generated near the inlet end of the ASF using a commercially available Perkin-Elmer Atomizer shown in Figure 2. This device was chosen because it produces minimal stress without reprocessing the bacterial slurry. Particle size distributions as well as the quantity of fluid atomized could be varied. By adjustment, the atomizer was operated to produce aerosol similar in size to those emitted from treatment facilities, with a MMD of 7 μm, as determined by characterizations with the Andersen sampler (8).

In an effort to provide a uniform bacterial aerosol distribution throughout the cross-sectional area of the ASF, two atomizers were used simultaneously. Additionally, thorough mixing of the aerosols with inlet air was induced through the deployment of a grid placed upwind of the atomizers. The grid was designed to provide small but sufficient turbulence to produce the desired mixing. With the above procedures, typical airborne concentrations of about 3.5×10^5 viable aerosol particles/m^3 of air were achieved. Aerosols thus produced were drawn down the tunnel and through various densities and types of vegetative filters.

The bacterial aerosols were characterized in planes perpendicular to the air flow both upwind and downwind of the vegetative filters by Andersen samplers containing standard methods agar and all-glass impingers, as shown in Figure 3. Sampling intervals of 1 or 2 min resulted in near optimum collections of bacteria for characterization with the Andersen samplers.

Andersen sampler plates were incubated at 30° for 12 to 18 hours. Using a relationship described by Andersen (8), the actual concentration

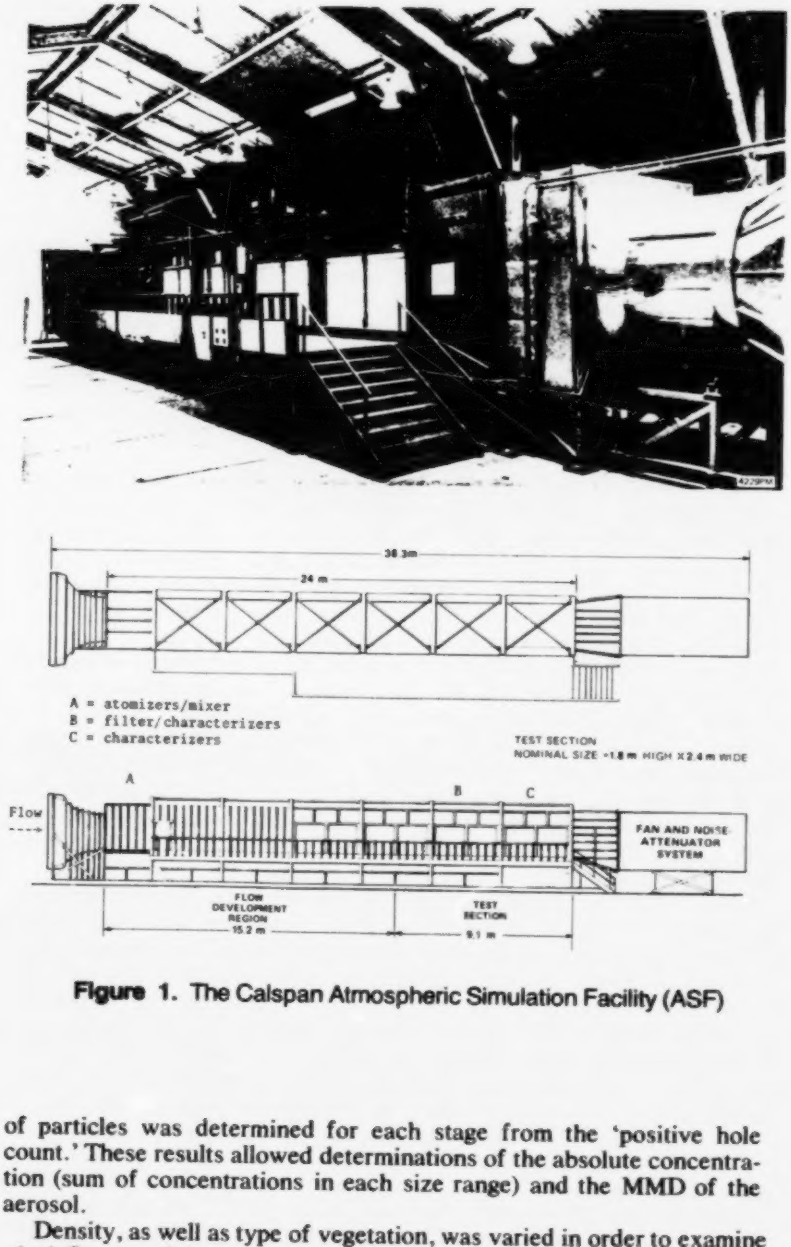
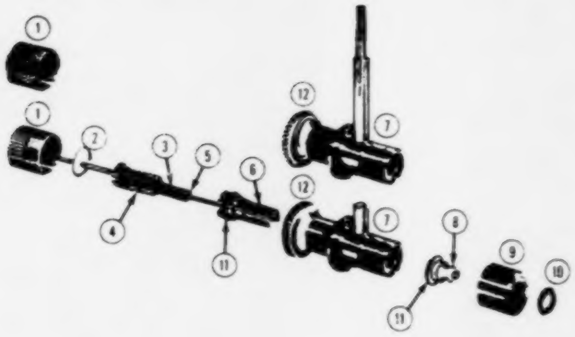

4229PM
36.3m
24 m
A = atomizers/mixer
B = filter/characterizers
C = characterizers
TEST SECTION
NOMINAL SIZE ~1.8 m HIGH X 2.4 m WIDE
A
B
C
Flow
FAN AND NOISE ATTENUATOR SYSTEM
FLOW DEVELOPMENT REGION
15.2 m
TEST SECTION
9.1 m

Figure 1. The Calspan Atmospheric Simulation Facility (ASF)

of particles was determined for each stage from the 'positive hole count.' These results allowed determinations of the absolute concentration (sum of concentrations in each size range) and the MMD of the aerosol.

Density, as well as type of vegetation, was varied in order to examine the influence of these parameters on the filtration efficiency of the vegetative filters as shown in Figures 4a and 4b. One type of evergreen, the White Spruce (*Picea glauca*), and two types of deciduous vegetation, the


1
1
2
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5
6
4
11
12
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12
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8
9
10
11

1 Knurled Knob
2 Washer
3 Sample Tubing and Capillary Assembly
4 Spring
5 O-ring
6 Insert
7 Nebulizer Body
8 Venturi
9 Rear End Cap
10 O-ring
11 O-ring (2)
12 Locking Ring

Figure 2. Exploded View of Atomizer

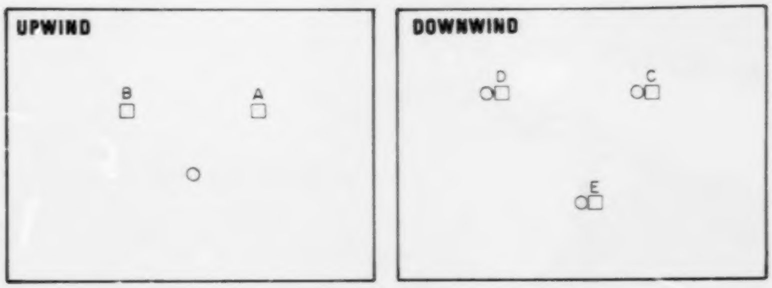

UPWIND
B
A
DOWNWIND
D
C
E

Figure 3. Approximate Positions Within the Cross-Section Plane of the ASF Perpendicular to the Air Flow of Andersen Samplers (□) and All-Glass Impingers (○) Upwind and Downwind of Vegetative Filter

Figure 4a. Construction Stage of Vegetative Filter

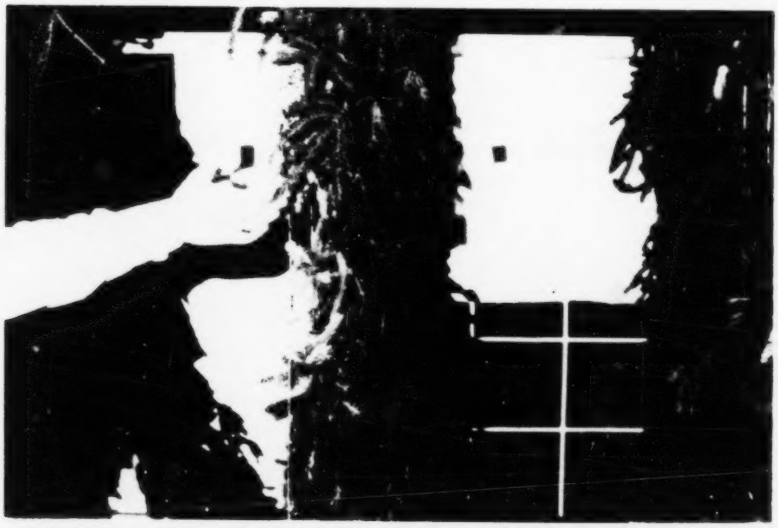


Figure 4b. Lateral View of Completed Vegetative Filter

Cottonwood (*Populus deltoides*), and the Black Willow (*Salix nigra*) were used in the trials. The vegetative filters were constructed on a wire grid across the entire cross section of the tunnel such that there were no obvious 'holes'. Variation in density of vegetation was achieved by the use of multiple vegetative filters stacked along the length of the ASF. A maximum of six vegetative panels were used. Vegetation for these filters was cut fresh at the beginning of each day, and each piece was supplied with a partially water-filled balloon tied to the cut stem to keep it in fresh condition during the trials. Particular species of each vegetation type were chosen on the basis of range, common to both the Chicago and Buffalo areas and on the basis of availability.

Wind speeds in the tunnel were varied to simulate those expected within the forest canopy. Normally, four different wind speeds of 0.4, 1.8, 3.1, and 4.9 m/sec were used for each filter arrangement.

Experimental Results

A total of 41 trials were conducted in the ASF. Of these, 20 actually represent the basic experimental data. The remaining 21 were preliminary trials performed to evaluate aerosol generation and characterization techniques as well as to assure that background counts of bacteria were not of sufficient levels to create interference.

The trials may be segregated into two groups based upon the type of vegetation used in a particular trial, either deciduous or evergreen. Beyond this basic segregation, other important experimental parameters that were considered were wind speed and vegetation density. The higher the wind speed the more likely particles will be filtered by impaction on vegetation elements.

While the decrease in aerosol concentration across the filter was an indication of filter efficiency, information on filter efficiency was also gained from measures of the change in MMD of aerosol spectra. The impaction mechanism which was expected to be responsible for removing most of the microbial aerosols should exhibit a dependence on aerosol particle size. That is, greater portions of the larger particles (>5 μm diameter) than of the smaller particles (<5 μm diameter) should be filtered by impaction. If such an occurrence were observed during the trials, the MMD of the aerosols would decrease due to the resulting smaller proportion of the total spectrum represented by larger particles.

Background counts of bacteria, performed before and after each series of tests with the vegetation in place, conclusively indicated that no bacterial particles were being reentrained from the surfaces of the vegetation.

Trials performed with Cottonwood resulted in a low filtration efficiency for microbial aerosols as indicated by low concentration reduction, shown in Figure 5. A maximum reduction for this type of vegetation of about 15% was achieved at the two intermediate wind speeds. At either extreme of the wind speed, no reduction in bacterial aerosol concentration was observed across the vegetative filter. Trials performed with Black Willow, on the other hand, produced more significant results. These results were unique in that a consistent, almost 50% reduction in the aerosol concentration was observed across the vegetative filter. The observed reduction in the concentration of bacterial aerosols by the Black Willow filter was independent of wind speed. There was also no observable variation in the MMD of the aerosol across the filter with Cottonwood (Figure 6).

It is possible that the unexpected decreases in aerosol collection by the vegetative filter with increasing wind speed were due to the formation of 'holes' in the vegetative filters. The filtration efficiency of Black Willow was further indicated by a decrease in MMD of the aerosol across the filter. The reduction of MMD was wind speed dependent with a maximum of about 30% at the highest wind speed and a minimum (actually a slight increase) at the lowest wind speed.

It was not known whether the superior collection efficiency of Black Willow is due to leaf shape, undulating leaf characteristics, or possible electrical charge accumulation on leaves. However, small wind speeds are sufficient for Black Willow to produce a significant filtration effect.

The observed decrease in bacterial aerosol concentration for dense evergreen filters was dependent upon wind speed (Figure 7) with a maximum of almost 45% collection occurring at the highest wind speed and a minimum of 10% at the lowest wind speed. For sparse evergreen filters, a decrease of more than 30% was observed in the bacterial aerosol concentration across the filter at the highest wind speed. The observed reduction in aerosol concentration with density of evergreen filters suggests a minimal dependence of filtration by White Spruce on the amount of vegetation.

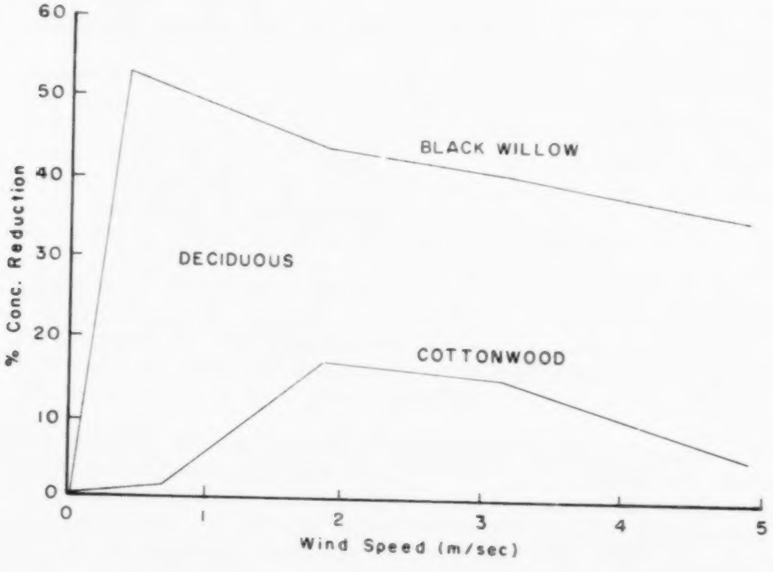


Figure 5. Percent Reduction in Aerosol Concentration as a Function of Wind Speed for Deciduous Vegetation

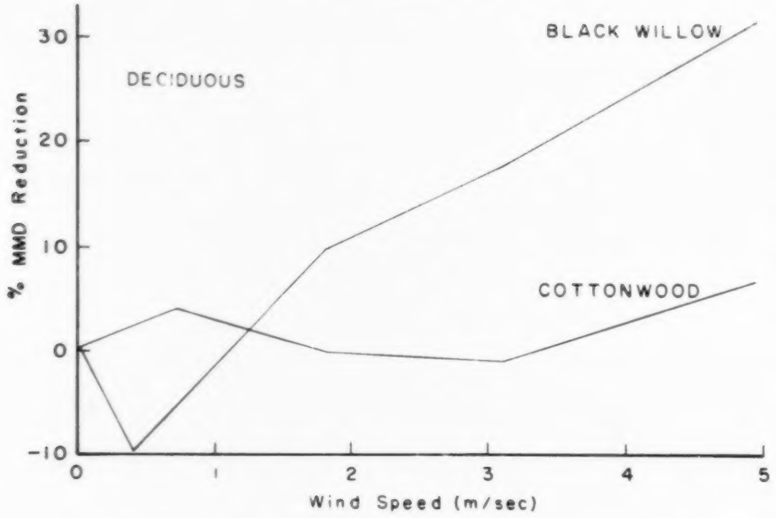


Figure 6. Percent Reduction in Mass Median Diameter (MMD) of Aerosol as a Function of Wind Speed for Deciduous Vegetation

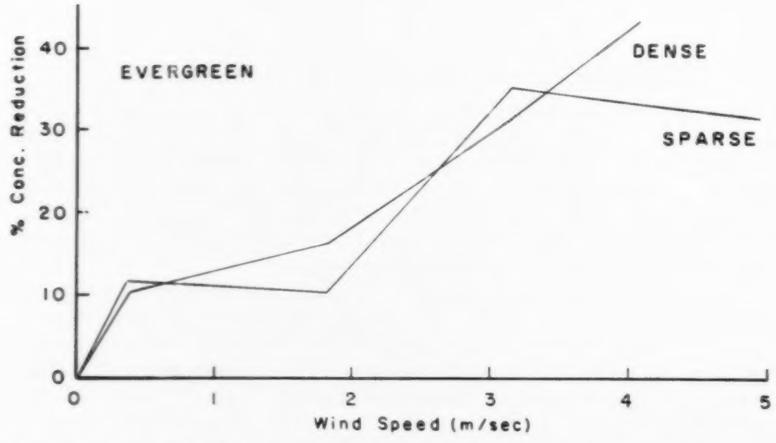


Figure 7. Percent Reduction in Aerosol Concentration as a Function of Wind Speed for Two Densities of Evergreen Vegetation

The reduction in MMD of the aerosol displayed less pronounced dependence on wind, but did exhibit some reduction at each of the higher wind speeds as shown in Figure 8. This reduction also displays no consistent dependence upon vegetation density. Both sets of data (concentration and MMD) do indicate dependence on the wind velocity except for sparse vegetation.

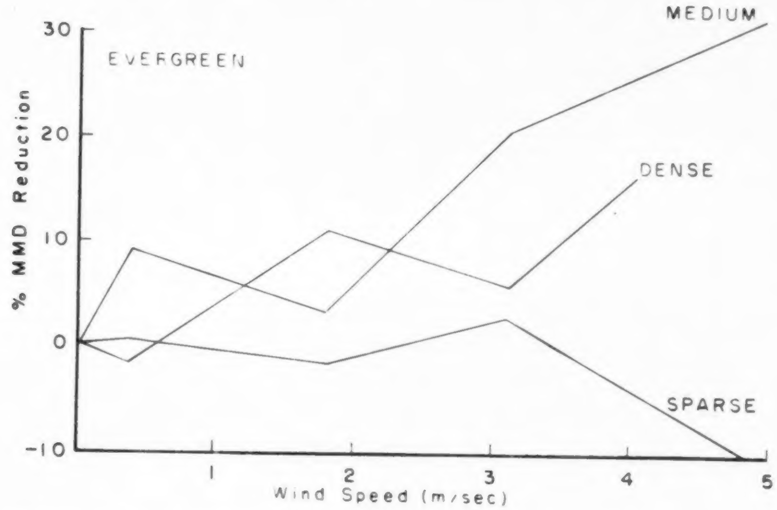


Figure 8. Percent Reduction in Mass Median Diameter (MMD) of Aerosol as a Function of Wind Speed for Various Densities of Evergreen Vegetation

AERODYNAMICS OF VEGETATIVE BARRIERS

As a result of the present study, which showed that the attenuation of microbial aerosols by filtration through a vegetative barrier was limited to not more than 50%, the question of the enhanced turbulent dispersion and dilution, that would be created by a vegetative barrier, became of greater interest. The literature was surveyed to investigate what is known about the aerodynamics of vegetative barriers and to what extent they may contribute to aerosol suppression.

The available literature contains dissertations, government reports and published papers describing a considerable volume of research into air flow, in and around a forest canopy (9-21). There is substantial agreement on the basic features of this type of flow, both from full-scale studies and from studies carried out on models in special wind tunnels simulating the atmospheric boundary layer. In addition there is a wide body of literature concerned with the adsorption and release of gases, including water vapor, within forest canopies. This literature covers certain concepts associated with interchange of gases with foliage, which are relevant to the current problem.

Most of the studies have been concerned with the flow through and over the trees near the upwind edge of an extensive forest, and in some cases, the flow leaving such a forest. However, since the most vigorous turbulent exchange takes place over a distance of a few tree heights into the forest, these reports cover the most important features of the forest-canopy flow, for our purposes.

Characteristics of the Forest-Canopy Flow

When the turbulent atmospheric boundary layer, after it has traversed a region of comparatively small scale roughness, encounters the upwind edge of a forest canopy, two significant things happen. The average wind trajectory (streamline) rises in order to carry most of the air, which approached below tree-top height, over the forest. Also, the sudden increase in surface roughness, characterized by the roughness length, z_o, of the logarithmic boundary layer, causes a jump in turbulent sheer-stress, or τ, near the upwind edge of the forest. Thus, a very strong mixing process exists for a horizontal distance of a few tree heights before the sheer-stress settles down to its new value characteristic of the roughness parameter, z_o, for the forest. The latter is a characteristic of the diffusion of heat or momentum within a boundary layer whenever there is a sudden change in surface temperature or surface shear-stress, respectively.

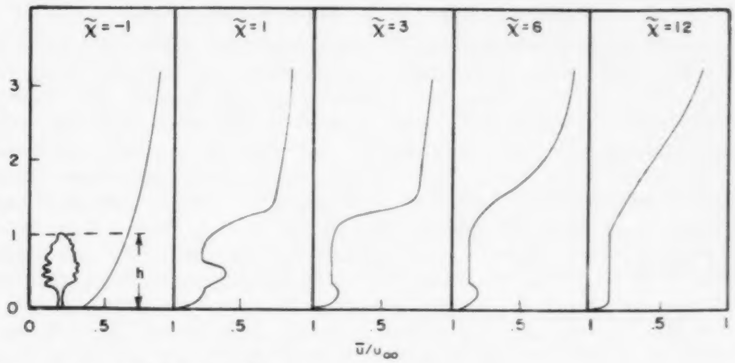
These two features govern much of what happens near the upwind edge of a forest. Most of the approaching air goes *over* the forest; some of it jets in amongst the tree trunks for a distance of a few tree heights. Thus most of the microbial aerosol carried in the air passes above the trees at the upwind edge. However, the large increase in turbulent shear-stress for the distance of a few tree heights produces a vigorous mixing action over the first few rows of trees, and this mixing carries down into the crowns of the trees. Hence, aerosol passing over the edge of the forest experiences a significant vertical pumping up and down through the foliage of the first few rows of trees, and, likewise, aerosol carried into the region of the trunks experiences some upward mixing from the same pumping action.

Mean Velocity Profiles

The mean velocity profiles within and above the forest canopy take the general forms, shown in Figure 9, taken from work of Hsi and Nath (13) for a model forest in a wind tunnel. The so-called jetting action at tree trunk level is clearly visible. In data presented by Kawatani and Sadek (15) the jetting action is even more noticeable and depends upon tree spacing. Figure 10, taken from data presented by these authors, shows the velocity profiles at a distance 5.6 tree heights (h) upwind of the forest, at the edge of the forest, and at 1.7 h into the forest. In the vicinity of the trunks the velocity may exceed the velocity at the same height upwind of the forest for about 2 h into the forest. This characteristic would be an important one to study in designing a vegetation barrier.

Turbulent Shear-Stress Distribution

A very clear effect of the sudden change in surface roughness, as the atmospheric boundary layer encounters a forest, has been demonstrated in another report by Hsi and Nath (12). Their work indicates the presence of high turbulent stresses at the upwind edge of the forest for a distance of one or two tree heights, and indicates that about 20 h into the forest is required before the stress settles down to its new steady value. The mixing created by this region of high shear-stress is the mechanism



h = HEIGHT OF TREES

χ = HORIZONTAL DISTANCE DOWNWIND OF EDGE OF FOREST

$\tilde{\chi} = \chi/h$

$\mathfrak{z}$ = HEIGHT ABOVE FLOOR OF FOREST (in units of h)

$\tilde{\mathfrak{z}} = \mathfrak{z}/h$

$\bar{u}$ = LOCAL MEAN VELOCITY

u_{∞} = REFERENCE VELOCITY AT REFERENCE HEIGHT WELL ABOVE FOREST CANOPY

Figure 9. Normalized Velocity Profiles Through a Forest Canopy—From 1 Tree Height Upwind of the Forest to a Distance of 12 Tree Heights into the Forest (13)

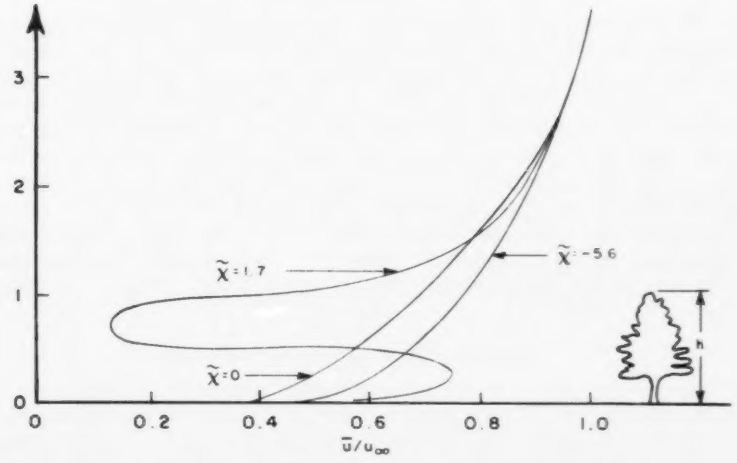
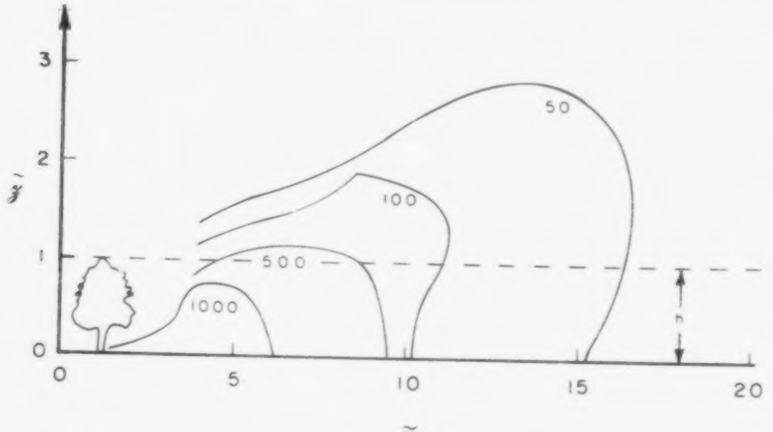
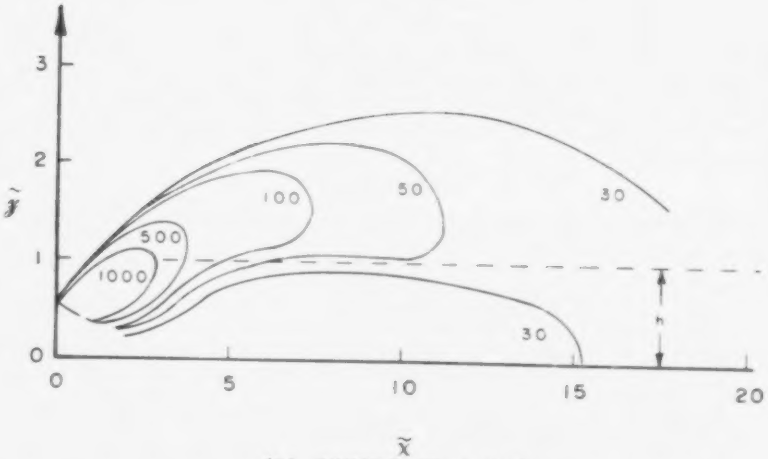


Figure 10. Normalized Velocity Profiles Near the Edge of a Forest—Showing the Jetting Action in the Region of the Trunks, Tree Spacing ≃ h (for symbol definitions, see Figure 9) (15)

responsible for diffusion patterns that would be exhibited for microbial aerosols released just upwind of a forest. Meroney and Yang (20) present many figures showing isoconcentration profiles for a variety of pollutant release conditions. Figure 11 is an example based on Figures 13 and 14 of their report. Here, concentration isopleths are shown for pollutant release at the upwind edge of a forest at two heights. It illustrates how the flow, which enters at the base of the forest, is mixed upwards into the flow above the canopy. It also shows how the flow passing over the canopy becomes mixed downwards into the forest. It is



(a) SOURCE AT GROUND LEVEL



(b) SOURCE AT 0.56h

Figure 11. Concentration Isopleths for a Source at the Upwind Edge of a Forest (For symbol definitions, see Figure 9) (19)

interesting to note that the mixing mechanism is quite strong at the upwind edge of a forest. As a result, aerosol released just upwind near ground level will be diffused to greater heights than would occur without a vegetative barrier. The pumping action through the canopy will also improve adsorption on the foliage, thus augmenting the filtration effects.

Discussion

In placing the experimental portions of this study in perspective with the literature survey, the following effects are evident: by itself, filtration of a microbial aerosol by a vegetative barrier cannot be considered effective. However, this study has shown that filtration effects are dwarfed by the expected reduction in aerosol concentration due to mixing and dilution of aerosol at the upwind edge of the forest barrier by orders of magnitude. The aerodynamic barrier that the forest represents provides a method of reducing the ambient aerosol concentration, not only by removal but principally by vertical dispersion and dilution. The additive effects of filtration with vertical diffusion and mixing make vegetative barriers an attractive alternative for aerosol suppression.

In the field, downwind, the influence of the barrier, in the absence of significant filtration, would show effects in reducing aerosol concentration primarily by physical loss of the aerosol through dilution and particulate fallout. In addition, viability decay of the microorganisms would further attenuate the aerosol. The major concern, however, because of the expected shallowness of planted barriers, has to be whether the vegetative barrier can significantly affect the close-in regions where microbial aerosol concentration may be high enough to be objectionable. This possible effect would require additional study.

In conclusion, it has been demonstrated that specific types and densities of vegetation may affect up to 50% reduction in microbial aerosol concentration(s) and MMD by the mechanism of filtration. Based upon these experimental results and a review of the literature, the dispersion effect of a barrier, in conjunction with the filtration effects, provides a mechanism for suppression of aerosols emanating from an aeration basin by orders of magnitude. It is concluded that vegetative barriers strategically placed can effectively suppress microbial aerosols from treatment basins.

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DISCUSSION

SPEAKER: On the data that you have, is it all on *Bacillus subtilis?*

DR. SPENDLOVE: Yes, it is all on *B. subtilis*. We did try *Escherichia coli* along with this, but we had problems with decay in the length of the chamber, and for that reason we gave up testing that organism.

SPEAKER: What about cells that are vegetative rather than spore formers? Do you expect a difference between spore formers and non-spore formers?

DR. SPENDLOVE: All of the *Bacillus subtilis* were spore formers and were all in the spore state. We didn't expect any decay for the distance, and our data indicated that. Where we had no vegetative filters there was no decay for the length of the chamber.

SPEAKER: Do these effects that you describe for forests also hold for trees that have lost their leaves during the cold half of the year?

DR. SPENDLOVE: Well of course there is some effect, but very little. We wanted to test both of them. I would recommend that we use vegetative barriers of coniferous trees that don't lose their leaves. Also, I think that the small needles on those types of trees present a greater surface area for chance of impaction than you will find on most deciduous trees.

DR. FLIERMANS: When you talk about the density of the canopy, are you talking about moderate sparse or dense?

DR. SPENDLOVE: What we are talking about is the width of the barrier. We wanted to get some impression of the effect that the width might have. Of course, the greater the width, the greater the chance for an aerosol particle to impact out on a piece of vegetation.

DR. FLIERMANS: Can that be related to the tree population per square foot?

DR. SPENDLOVE: We made no attempt to relate sparse, medium, or dense to any population. This was simply to get some idea of the effect that the width of the barrier might have on filtration.

MR. SCHWARTZ: I wonder if the lesson this might have is that we site wastewater treatment plants for areas of maximum turbulence?

DR. SPENDLOVE: I would say so. Also, of course, if aerosols are shown to be a problem somewhere and you can get an instant barrier by putting a berm around the basin as high as you could, even 10 to 15 feet, and 50 feet thick let's say, an earthen berm will create the same effect of pushing the aerosol up. This could be a temporary expedient and you could plant the vegetative cover on top of that, and each year that it grows you get better results.

MR. SCHWARTZ: Well, the one plant which I have seen is built very similarly to a wall, with a very high barrier all around. In looking at some preliminary data that was obtained, it seemed like there was quite a bit of verticle mixing. The bacteria counts were really quite similar to those upwind as far as aerosol was concerned.

MR. LINDAHL: How many rows of trees would constitute a forest?

DR. SPENDLOVE: Well, I couldn't say. The thicker you could make it the better, up to about a hundred feet. But I would think that 30 to 50 feet of dense trees with underbrush should give you sufficient barrier to create the desired turbulence.

MR. LINDAHL: Well, about three rows of trees wouldn't quite qualify.

DR. SPENDLOVE: It would help. Everything helps.

SPEAKER: What about resuspension off of those trees? It may be more of a problem with deciduous than coniferous.

DR. SPENDLOVE: As I mentioned in my report, we tested for reentrainment off of the vegetation and found none.

SPEAKER: Vegetation?

DR. SPENDLOVE: Yes. Now, one of the things that you should remember is that if it is impacted it takes considerable energy to reentrain it, like a hurricane or a tornado. Even if that happened, we have had the particles there for sufficient time that viability decay would have completely inactivated it.

Assessment of Health Effects Panel Discussion

Chairman—Herbert R. Pahren

US EPA, HERL, Cincinnati, Ohio

Panel Members
Leland J. McCabe, *US EPA*
Cecil Lue-Hing, *MSD of Greater Chicago*
Mitchell Singal, *NIOSH*
C. Scott Clark, *University of Cincinnati*

MR. PAHREN. We will have a panel discussion on what everything means at this point. In selecting the panel members, I tried to obtain persons with different viewpoints, representing different interests.

One is an individual from EPA. Another person is from the National Institute for Occupational Safety and Health. Another interest I wanted to have represented was one of the principal investigators of some of the epidemiology studies that have been conducted over the past several years and, lastly, the interest of someone involved in managing a sewage treatment system. So, the first panel member will be Mr. Lee McCabe.

MR. McCABE. Henry Longest asked if the challenge was only scientific, and I would have to answer, based on what we have heard during the last two and a half days, that we probably do not have the complete, scientific know-how to detect minute differences with his problem of sewage treatment plant aerosols.

We have spent somewhat over $3 million during the last several years and have to conclude that we cannot measure subtle differences, if they exist, in health effects from exposure to these microbes. Considering the impact on the agency, this has been research money constructively spent. The effort has not been excessive or duplicative, but as research it has shown that our methods may need further refinement.

Mr. Longest was apparently concerned that assessments would be made that would substantially increase the cost of sewage treatment. If we make our assessment on the sewer and wastewater treatment worker data, we should be able to save the government considerable sums in the construction grants program. There appears to be no hazard from sewage and every home can have a cesspool in the backyard to take care of the liquid waste. As our colleague from Baylor has indicated, each family would be exposed to its own sewage and that would not be a hazard.

In order to say that sewage treatment plants are not hazardous to the neighbors, we must have instruments that can measure the effect, if there really is one. Bob Miday addressed the problem of the power of the test to detect a real effect. We used the best and most sensitive methods known but our illness inquiry system, serological epidemiology, and check of infection rates did not find an effect. We must show that we have a method to detect an effect in a maximally-exposed population. In other words, we must have the equivalent of positive controls to prove that our methodology has sufficient sensitivity to detect an effect, if there is one. Maybe our sample sizes have been too small and we will have to pool results from several studies, but the University of Cincinnati group doesn't even show minor differences in the right direction. If Scott Clark studied every new worker that was hired to work at the plants, what else could he do? Would Dr. Rylander's techniques be more usable?

Some of us took comfort in that at least we had a worst case report from Israel, but now Mr. Fattal tells us that this is most likely not so.

The effects of exposure to pathogens on enteric disease have been measured. We have just completed a series of studies relating bacterial indicators of water quality to gastrointestinal symptoms in swimmers (1). Even as a child I was able to show the effects of privies on dysentery rates (2). Is the adult somewhat refractory to infections even when lacking "measurable" antibody? Will Scott Clark have to study a group of Cub Scouts, led by a 70-year-old den mother, that clean up a polluted riverbank?

The chemical epidemiologists seem to have solved their problem with a few studies. Effects occur and they can be measured. All that is needed is to keep the neighborhood exposure below the TLV or, maybe better, to keep it below upwind background.

The concept of getting the viable microorganism count below background density should also be considered, but I am not sure we know how to measure the viable count in the proper way. We need to be measuring something that relates to infectious dose. Is it possible that what has been called the aerosol shock is really the reducing of the size of microbiological clumps? Maybe the aerosol is only a set of single viable organisms. These could be less than a minimum infective dose. We may need an animal exposure experiment to get at this concept. If the exposed person must be susceptible to be able to measure an effect, how can such a study be conducted? Children were studied at Tigard, Oregon; and getting blasted only a few days per year was not reflected in school absenteeism.

Dr. Fannin's paper did not talk about children except to note that the rates were age adjusted. When he adjusted for everything, there was a higher rate at 600 m, and a look at the tables in the published report (3) gave a hint that children should be examined more closely. More years of data might have to be collected and studied to get a reasonable number in just younger ages.

Don Johnson also reported an effect on neighbors; some illnesses and infections were higher after start-up of operation. The illness effect looks like it is greater in children to me, but I did not see data on age for the infections in their published report (4). Here we may also have too small a population of the younger ages, but maybe another study could be done concentrating on the young when some other plant is started up.

It would be best to have comments by Fannin and Johnson on how they see the effects on the younger ages.

If we are requested to continue the health effects studies, we would do well to research also the cost of aerosol supression; then more realistic trade-offs could be made in the future.

If suppression were very costly, we would need unequivocal health effects to justify the cost; but if some less costly techniques were available, health effects data would not need to be as firm. From what we have heard, there would seem to be little justification for large expenditures to contain aerosols based on a national policy, or even for a single plant. The designer of sewage treatment plants must continue to be concerned, however, and do what can be done to minimize aerosols. Here is where the more-than-scientific considerations are involved—the public must feel that their interests are considered.

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DISCUSSION

DR. LUE-HING: I think I will start by asking a question of Lee. What was your dose-response measuring instrument for your privy testing?

MR. McCABE: We did rectal swabs for *Shigella* on the kids, and we demonstrated that before, during, and after, the rates were different. A simple thing.

DR. LUE-HING: Well, I am happy because it seems to me that we were using the same instrument in the epidemiological studies. So, we do have the measuring technology, Lee, for looking at health effects.

To indicate that my comments are totally objective, I did not write anything until this morning. In fact, I consulted with my colleagues last night and I went to sleep, didn't think about it, and wrote most of my notes during Lee's presentation. I was here for the last 2 days and I heard the same presentations that Lee did, and I disagree with his assessment of the information that I think we both heard.

If we start with Henry Longest again, he posed a very challenging question; and I still believe that, in our attempt to answer that question, we have to come down to earth a little bit. I have no objections to being in the clouds, but there are times when we need to come down to earth. I listened to Dr. Cliver, and I have to agree with him that the population that is least at risk are the residents. In his descending order of risk, it would be the workers, the visitors to plants, and, finally, the residents in the vicinity of plants.

It was indicated by Dr. Rylander, through my interpretation of his data, that only in specialized circumstances such as unusual confinement situations was it shown that the sewage treatment plant environment may have some effects on the health of the worker. We are not talking about aerosols in the same context of the symposium but, rather, we are talking about a dust-related type of situation.

Dr. Fannin's work was reviewed by Lee. I have no difficulty with Kirby's work. I think his report also showed that sewage treatment plants can be good neighbors. Dr. Johnson's work on the John Egan plant indicated to me that, living next to a sewage treatment plant does not expose you to any additional risk. David Camann's work on the school children again says to me, "We are not exposing our residents to additional risk." And, incidentally, we, too, have a grade school next door to one of our suburban plants in the township of Hanover Park. So, we do share the experience with Mr. Camann.

Perhaps one of the most comprehensive, though short-lived, experiments yet performed in this area, involving epidemiological characterization and assessment, was the work by Northrop of the University of Illinois. Incidentally, it may be good for the audience to know that my organization is involved in most of the field experimental work reported on in the last two days, either directly or indirectly. We were involved with Scott Clark on his study. We loaned the Northside plant to EPA for the study by Northrop. We loaned the Egan plant to EPA for a study by Southwest Research. We are now doing the suppression work and we are involved in bits and pieces of other studies reported in the last 2 days.

We do have an interest, and we are not afraid to know the truth because we feel that, if there is something out there that we need to know, we want to be the first to know it. In these days of funding at 75% and the enormous cost that we face in Chicago, we just want to be first in line. So, we are interested.

I had some difficulty with the Israeli work when it first appeared in *Science*, and I was asked to review that paper when it was presented in Melbourne. I could not be there personally but a colleague of mine read my critique. I am very encouraged that Dr. Fattal's group has decided to reevaluate that particular study. I am encouraged because that work has been quoted very extensively throughout the world and I run into it almost every place I go.

However, having talked with him the last 2 days and having seen the new information he is presenting, I am more convinced now that my critique in 1976 was correct. I feel confident that, when his work is completed, we will reach a conclusion that spray irrigation does not present any significant additional risk to the community.

As a participant in Scott Clark's work, to some extent, I know of it and I have been with it for some time. The conclusions reached also convince me that the sewage treatment environment does not pose any significant risk to the worker and less so to residents close to sewage treatment plants.

I was particularly encouraged by the assessment and presentation of Dr. Linnemann who, as a physician, could not afford the luxury of making statistical diagnoses. He treated the data very well, and I feel that we are fortunate that the establishment of significance was not left up to statistics alone but to the judgment of a qualified medical practitioner. I have nothing against statistics. I am just afraid sometimes that when two numbers collide, and the statistician has to make a choice he goes in the direction of the heavier number.

Dr. Sekla's work also indicated to me that the sewage treatment environment does not pose any additional significant risk to the worker. Here again we have a situation where the environment was confined, and there was far less opportunity for normal outdoor mixing. There appears to be some information in the data she presented that this could create some difficulty for the worker, but not the residents close by the facility.

We are involved in the review of death certificates of former workers of the Southwest District in Chicago. When the request was made, the records personnel and my boss came to me and asked, "What the hell do we do?" I said, "Give them the records. If there is anything in there you guys need to know, you had better know it in a hurry. Give them the records." So, we decided to participate and to cooperate. Again, we want to know what is in those records because, if something is wrong, we want to be the first to correct it.

Following all of this information, we examined the small data base that we were able to generate on the basis of our aerosol suppression study. After putting it all together, I have no difficulty at all in concluding that the proper operation of sewage treatment facilities will not pose any additional significant risk to the community.

I noticed, in the last 2 or 3 days, that some of my colleagues, including my friend Lee, lament the fact that we don't find any responses or we don't find any effects. I am not surprised; they are not there. It is not because our measurement technology isn't good enough. It is good enough. I have always been prepared to spend money to improve our measurement technology, but I think we have ample technology today. We are not finding responses because the responses just aren't there. It is not because we are not able to measure them.

I am encouraged that Lee concluded that there is no justification for massive expenditures for suppression. I certainly agree. I will support funds for continued work because, while I am not a public health-related man *per se*, I am fully aware of the need to maintain our vigilance and to remove any last vestige of doubt. I am happy for people like Lee McCabe because, without them, there will always be some residual doubt, and I would be quite prepared to support additional work in this area.

Before I close, I would like to say a few nice words for the EPA. Those of you who know me well enough know I don't do it too often, not because I am giving them a bad deal, but I don't think they deserve all of the praise too frequently. In this instance, I think the EPA, and particularly within the context of our meeting, the health effects group should be commended.

I thought that the program had spent in the area of $12 million and I was prepared to say, "You did a good job for $12 million," but when you said it was about $3 million, I have to double that praise. Five years ago, I could not comfortably arrive at the conclusions I have today. While it was my gut feeling that my conclusions were valid then, I couldn't prove them, at least as effectively as I can today. For the $3 million that these guys have spent, I think they have gotten a very good buy for their buck. They have answered a lot of questions, not all, but the most critical ones. I believe that the operating parts of your agency can now make the type of judgments that are necessary concerning aerosols.

I believe we have arrived at the point where I personally can say, based on what I have heard in the last 2 days, I do not see any significant additional risk to residents around sewage treatment facilities.

MR. PAHREN: Thank you, Cecil. Also, I thank you for your kind words regarding EPA. EPA seems to always be in the middle. On some of our regulations, we are sued by both sides, so praise isn't coming that frequently and it is appreciated, especially if it is coming from you, Cecil.

MR. FATTAL: (Submitted for the proceedings in response to Dr. Lue-Hing's comment on the 1976 article in *Science*—Ed.) The data of the first study (*Science* paper 1976) cannot be compared to those of the present retrospective study as they have entirely different data bases. The most obvious and important difference is that the *Science* paper included disease cases reported to the Ministry of Health, including those cases from volunteers and temporary residents. The present retrospective study is based on present kibbutz clinic records which, in general, do not include those cases, and to our sorrow, we discovered that kibbutz clinics do not keep files for volunteer and temporary residents after they leave. This means that the potentially most susceptible group has been lost. This might lead to a totally skewed picture of what really happened in years past. The only way to overcome this constraint is through a prospective study which will include temporary workers and volunteers as well as permanent residents.

Another difference between the two studies is that they do not cover the identical time periods. In the *Science* paper, the *Salmonella* data was drawn from the records of the Ministry of Health for the years 1969 to 1974, a 5-year period, while the typhoid data covered years 1965 to 1974, a 10-year period.

We decided for reasons of uniformity and convenience to restrict our data collection for the current retrospective study from 1974-1977, a 4-year period. Thus, the time periods of the study are not identical, which might provide another explanation for the lack of congruence or correlation in the overall results.

This may not explain the difference in results to the two studies, but it is important to keep these factors in mind. Only when the prospective 3-year study is completed can we arrive at a definite conclusion.

DR. SINGAL: Without trying to be too repetitious, let me just say that my assessment of the epidemiologic presentations yesterday was that the studies of health effects in the community around wastewater treatment plants, in general, showed little evidence of infection attributable to treatment plant aerosols and no convincing evidence of clinical illness. But, to briefly review the deficiencies that plagued these studies —deficiencies in the circumstances, not in the quality of the study necessarily—there seemed to be very few people living closer than a quarter to a half a mile from the site of the aerosol generation, and even those within half a mile to a mile range, there were often insufficient numbers of families to adequately detect illnesses that you might expect to have with a low prevalence.

Likewise, in workers of wastewater treatment plants, there seemed to be little evidence of increased rates of infection or clinical illness due to microbiologic agents and, thus far, no convincing evidence of increased mortality. On the contrary, we have seen evidence of adverse short-term health effects due to acute chemical exposures and absorption of chemicals to which there was low level or chronic continuous exposure and, presumably, in the near future, we will see whether there is any evidence that this is associated with any health effects.

To the question of whether there is or is not substantial health hazard to the community or to the workers of the treatment plants from exposure to aerosols generated in the treatment plants, I would conclude that, in the absence of any unusual circumstances resulting in unusual exposure to the workers, there probably is no substantial health hazard from aerosolization of microbiologic agents. I will temper that with the realization of the conceptual and statistical difficulties of proving a negative.

I would propose two methods of investigating this problem that haven't been addressed. One of them is a thorough investigation of outbreaks of infectious diseases that occur in the vicinity of treatment plants. I am not aware that this has been recorded, or that such outbreaks have been reported or suspected, but certainly, if one does, it should be thoroughly investigated. As somewhat of a precedent for this, associated with the investigation of the contamination of the Louisville sewage treatment plant, there was a concurrent investigation of the community surrounding the treatment plant for evidence of the same effects that were reported by the workers. In this case, we had a defined time period when we might expect these effects and we had specific effects to look for. The survey involved 212 residents, and there was no indication that the community residents suffered the same effects as the workers.

The other approach that might be worth investigating for the effects of microbiologic agents is to look at the surveillance data that is routinely collected by local and state health departments. In every state, Hepatitis A is a reportable disease. In most, if not all states, *Salmonella* and *Shigella* laboratory surveillance is conducted. Most state health departments do most of the viral serologic work for viruses of public health concern in the states, particularly for enteroviruses. Also, many state health laboratories do a substantial amount of parasitic identification and, even though they may not do the serology, they act as the conduit for parasitic serology to the Center for Disease Control.

DR. CLARK: I would like to take advantage of being the last of the panel to first respond to some of my fellow panel members' remarks. After that a few specific remarks will be made on what else has been said these past $2^1/_2$ days.

Lee McCabe's questioning of whether the most sensitive health effects assessment method has been used on an adequate number of worst-case exposures is a very important one. When we laid the plans for our study almost 10 years ago, I thought that the worst cases of wastewater exposures in Cincinnati were among the sewer maintenance workers. That is still my opinion today. However, because of a city moratorium on hiring new workers, we were only able to recruit 9 who remained in our study for a minimum of 12 months. The newly employed activated sludge treatment workers recruited into the study were employed at recently completed activated sludge treatment plant facilities in Cincinnati and Memphis. The Chicago treatment plants from which workers were recruited, while not as new as those in Cincinnati and Memphis, nevertheless were well maintained, up-to-date, activated sludge treatment plants. In general, therefore, the activated sludge plant workers in our study were not working in worst-case situations. If we had attempted to recruit workers in the most exposed positions we would have focussed on different groups of employees. In Chicago, for example, employees at the sludge heat drying facility would likely have been chosen. Exposures at this facility, however, are not representative of those at typical modern activated sludge treatment operations. Sludge heat drying facilities, such as the one in Chicago, are very limited in number in this country. Certain other enclosed environments at wastewater treatment plants, where the contaminants do not disperse or die off as rapidly as they do in open air situations, would be likely to represent more of a potential health risk than average outdoor environments at the plants.

Lee McCabe's somewhat jestful suggestion that we study a group of Cub Scouts and their den mother while they are cleaning up a polluted riverbank has some merit. For testing the adequacy of the study methodology, however, I would suggest that we focus on den mothers rather than on the cub scouts who would likely be a major pathway for infectious diseases transmission to each other. The cub scouts could also serve as a potential health risk to den mothers. The den mothers should be recruited into the study before they undertake their responsibilities with the cub scouts. Many alternatives to den mothers exist, such as persons just beginning student teaching of young children.

The health effects studies performed thus far do not seem to justify large expenditures for aerosol suppression, a viewpoint also expressed by panel members McCabe and Lue-Hing. I agree with Cecil Lue-Hing that some research and development effort should continue in this area. Earlier this year I had an opportunity to visit a Los Angeles County wastewater treatment plant that had installed removable covers over the top of the aeration basins. The purpose of the covers was not to suppress airborne bacteria and viruses, but rather for odor control thought necessary because of local complaints. As I recall air beneath the covers was used as a source of air for the plant blowers, further reducing the release of odors. Existing aeration basin covers, such as these, warrant examination for study of their utility in reducing viable aerosol emission. Activated sludge treatment plants using pure oxygen, rather than air, as a source of oxygen for the microbes, should also be considered for their aerosol suppression characteristics which result from their having covers on their aeration tanks to permit recovery of oxygen. Any added cost of the oxygen systems over those using air should be compared to the cost of suppression devices installed on systems using air. In colder climates, some increase in the plant efficiency may also result from covered aeration tanks maintaining higher wastewater temperatures. Care must be taken in the examination of various techniques for aerosol suppression to insure that workers are not subjected to undue safety risks as well as other hazards.

Mitch Singal offered two alternative approaches to study wastewater treatment plant-caused health effects—the investigation of outbreaks in the vicinity of treatment plants and the investigation of surveillance data routinely collected by local and state health departments. The first approach could be expanded to include possible outbreaks among treatment plant personnel as well. My colleagues at EPA and I are contacted from time to time regarding suspected outbreaks at sewage treatment plants. In one such instance involving chemical exposure in Memphis, Tennessee, we were fortunate enough to have a routine infectious disease study underway at the same plant and were able to conduct a limited investigation. Vic Elia reported on some of the results of it yesterday. This investigation, as well as the one conducted by NIOSH in Louisville, Kentucky, and reported by Kominsky 2 days ago, have provided very useful information regarding the potential for chemical exposure of workers at wastewater treatment plants. Those exposures are likely to be intermittent in nature and therefore not amenable to study except when special conditions prevail.

The second approach suggested by Dr. Singal, examination of routine health department surveillance data, was attempted a number of years ago for Hepatitis A by fellow panel member Lee McCabe and a colleague of his (1). At the time, little data was available for other infectious diseases. They concluded that in Ohio, Hepatitis A rates among sewage treatment plant personnel appeared to be higher than among the rest of the population. This approach might yield useful information if attempted again.

There are several comments that I want to make on some of the presentations made during the previous 2 days. The studies of exposures of wastewater treatment plant personnel to organic chemical emissions reported by Kominsky and by Elia *et al.* seem to indicate that the acute effects subside rather rapidly after the exposure has ended. What isn't known are the long term effects. In the case of the Memphis situation, the exposure appears to be a continuous one of variable magnitude that has thus far lasted more than 2 years.

Rylander and Lundholm's work has been of interest to us for several years. Their initial study that came to our attention reported adverse effects of exposure to heat dried sludge. More recently, some of these same responses, such as elevated immunoglobulins and excess gastrointestinal symptoms occurred in workers at regular activated sludge plants. We have not found consistently elevated immunoglobulins among sewage-exposed workers in our study but have detected higher rates of gastrointestinal illness among workers newly employed in wastewater treatment plants. Rylander and Lundholm suggest that endotoxins are responsible for many of the adverse effects observed. We are currently including an evaluation of this exposure agent in our study of wastewater treatment plant sludge composting workers.

Results of the Tigard, Oregon, school attendance monitoring study should be used with caution because of the many factors unrelated to the nearby treatment plant that may affect school attendance, as the investigators indicated. Nonetheless, I think the observation that foam from the aeration tanks can be seen depositing on the school playground is evidence enough that the wastewater treatment plant is located too close to the school. The report by Fattal yesterday on their follow-up to the retrospective study of Israeli kibbutzim using wastewater spray irrigation suggest results different from those in their earlier report on this study. The new evidence would seem to indicate that, for the time being, the kibbutzim study results should not be cited as conclusive evidence of an adverse effect of wastewater spray irrigation.

The Copenhagen, Denmark, sewer worker study discussed by Dean is of interest primarily because of the elevated levels of immunoglobulin, and the high proportion of workers who die during their first year of retirement. Elevated immunoglobulins were also reported in wastewater treatment plant workers in Sweden by Rylander and Lundholm. Our interim evaluation of data on a mortality study of former wastewater treatment plant employees of the Metropolitan Sanitary District of Greater Chicago did not reveal such a high percentage of deaths early in retirement.

The study of Manitoba, Canada, wastewater treatment plant workers detected sinusitis among the workers that started upon exposure to the work environment and diminished after leaving work. They suggest that an allergen might be involved. Other findings of the study such as an excess of nasal disorders warrant follow-up.

In our study of wastewater workers, which was reported on extensively yesterday, indications of increased risk due to wastewater exposure have thus far been very few. In a prospective study of the relatively small population groups involved, with the inherent inability to control the hiring of new workers and their longevity of employment, certain imbalances of age and race are difficult to avoid. However, after careful analyses, we do not think that these differences affected the study results. Our initial objective of determining the sensitivity of the seroepidemiologic approach was not fully achieved because of the untimely moratorium on hiring of new sewer maintenance employees.

In conclusion, the results of the last 2½ days seem to indicate that wastewater treatment plant workers' hazard, if any, is small from infectious disease agents. Such hazards to nearby residents do not appear to have been detected at all. However, the worst case of exposure of either worker or neighbor has almost certainly not been investigated. Where acute exposure to organic chemicals has been expected, it has not been difficult to detect measurable effects.

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DISCUSSION

MR. PAHREN: Next, I would like to give the four panelists an opportunity to cross examine each other. Who would want to ask the first question?

DR. LUE-HING: I would like to make a few comments, which I probably should have made earlier. Dr. Singal brought it to my attention when he indicated his concern for the size of the resident population in the vicinity of its sewage treatment facility. The general pattern is for the immediate vicinity of a sewage treatment plant to be thinly populated.

However, in spite of that, the work done by Northrop of the University of Illinois on our Northside plant included in the test zone, not a number of families selected for testing by Northrop, but the test zone defined by the experiment contained over 16 thousand people. Without having the statistics in front of me, I can easily say that this population is greater than 40 percent of the cities in the State of Ohio. That is a lot of people.

The fact that Northrop selected 300 families indicated to me that he had a wide selection. He could have selected 1,000 if he had wanted to. There was not enough money in the budget to study 1,000 people, and I think Northrop and his group are intelligent enough to know that you don't need to study 2,000 families. You can do it with less if you design experiments properly and conduct your study to take care of that small population. Larger populations naturally are more desirable.

There is one other point which I have to comment on again. That is the fact that we don't find responses simply because they are not there. We should not forget that we have conditioned ourselves in the last 20 years to expect trouble, and we are not yet prepared to accept the fact that we were run off. We have to face up to the fact that we made it by crawling, and we will forever blame the lack of responses on measurement technology unless we come to grips with the fact that we are not really going to find the type of tragedy that some individuals predict, especially if they use a model.

So, I am happy that the measurement technology is adequate and that we are not finding these responses because they just aren't there.

DR. SINGAL: My comment about the sample size didn't have to do with the fact that he selected 305 out of 16,000. It had to do with the fact that if there is an effect, it is most likely very minimal and very subtle, and you wouldn't expect to see it out at a half mile or even beyond a quarter of a mile where most of these 16,000 people live. You would expect to see it up close to the source, and my comment on sample size had to do with the fact that even though there were 16 thousand people living in the test area, most of those people didn't live close enough to the plant to be exposed.

DR. LUE-HING: I think I would agree with you if there were any exposure at all. I think you are quite safe if you are 50 feet away.

MR. PAHREN: At the Northside plant where Dr. Northrop studied, I think the distances were measured from the center of the aeration basins. As I recall that site, there are houses right across the street on the west side. Do you know the distance between the edge of the aeration basin and the houses, Cecil?

DR. LUE-HING: I don't recall.

DR. NORTHROP: Thirty houses are within a quarter of a mile.

MR. McCABE: Well, I think Scott and Mitch both agreed that we ought to conduct the studies like a dose response, and you ought to have some place where you are getting a response. I don't think the conclusion is that we didn't see a response because there wasn't any. Somehow I think we should have been seeing something in the workers or we were not measuring the right thing.

We are not going about it the right way if we don't see something in the workers. Other than that, we shouldn't bother to build sewage treatment plants. Dump it in a stream.

DR. SINGAL: I think Scott said, the workers may not be the people who you might expect to show effects. There are no children, there are no old people, there are no debilitated people. Some of the organisms that were mentioned as problems, like *Klebsiella* and *Pseudomonas*, are mainly opportunistic pathogens that need a compromised host in order to cause a clinical illness. So again, you wouldn't expect these organisms to cause problems in generally healthy workers.

MR. PAHREN: How serious are some of the infectious diseases that the workers might get?

DR. SINGAL: Well, most *Salmonella* and *Shigella* infections are a matter of a few days illness, but they can be more serious. Parasitic infections aren't necessarily disabling, but they are unpleasant and unesthetic. Viral infections are not a big problem. As was mentioned, most of those poliovirus isolates and serologic responses were likely due to vaccine strains rather than wild strains. Enterovirus infections and other gastroenteritis are disabling for a day or two for the most part.

DR. LUE-HING: I do believe we might take some time to develop a practical methodology in the area of virus identification and enumeration. One of the problems we have is the inability to compare notes between laboratories. I think it is important that we develop some language where we can talk and understand each other in terms of what is a virus; how many do we have; and how do we go about counting them, identifying them, and standardizing the methodology for doing this.

DR. LUND: Did you study surface aerators or deep aerators?

DR. CLARK: Our plants have the porous plate diffusers at the bottom so your point is well taken. The surface aerators could have much more effect. Part of our reason for looking at the plants with subsurface aerators was that these were planned for the plant near the Chicago airport.

DR. JOHNSON: I think in all of our health studies and population studies that we lacked sufficient population within about 400 meters, particularly children. In our Egan plant studies we did expect to emphasize preschool children and school children with approximately half of the population. We did that and it still was not sufficient because there simply weren't that many people living there. Even the school we studied was 400 meters from the aeration basin.

I would like to make a comment now about the help we got from the Metropolitan Sanitary District personnel. They were extremely helpful and I would also like to make a comment that our conclusions were based on that plant relative to operations at that plant.

SPEAKER: If there were any effects as a result of the operation of treatment processes, there should have been some kind of evidence by this time. I don't know why in the recent years, some people are jumping on the bandwagon of research regarding aerosol effects.

DR. LUE-HING: Well, I have to agree with the gentleman on his feeling toward the recent popularity of aerosol work. In this country the incentive is money, and it is a very good incentive. I have no objection to that incentive. The sewage treatment plants constructed since the 1900's have been generating aerosols across this country. In Chicago, we don't measure aeration tanks in square feet. We measure them in acres.

If you remember the picture I showed yesterday, it was approximately a quarter of a mile across the aeration tanks. At this plant where we pump almost a billion gallons of sewage every day, we do have residents within, I would say, 250 ft of these aeration tanks.

They have lived there for decades. We are not aware of any problems. We can't get our operators to retire. We have to keep extending their retirement. At retirement age they keep asking for extensions. They don't get sick.

DR. DEAN: Why is there this emphasis on aerosols? I think it was pointed out in one of the early papers that many of the objections to odors and aerosols and virus infections are really secondary objections. The real objection is the people don't want the big city pushing down on them and telling them what to do.

We have had a great many objections of this sort where people are building their own power base by raising objections to what is not really related to the problem at hand, but is a handle they can use. We see the reverse done. We see recommendations for restrictions on sewer connections but what is really wanted is a rezoning ordinance. It is easier to restrict the load on the sewage plant and thus keep people from building more houses than it is to put in the zoning laws. There are a great many examples like this, and a lot of the objections to aerosols are probably not really based on aerosols.

DR. AKIN: Just a comment about the direction of future virus work. Traditionally, environmental virology has dealt with the enteroviruses because we had the tools for their *in vitro* study. The environmental transmission of disease produced by these viruses is difficult to study because most infections occur in children and are asymptomatic; also, a wide variety of symptoms are produced in those that do manifest disease. It appears that we are now obtaining the tools for *in vitro* study of the viruses that have been shown epidemiologically to produce waterborne disease—namely, Hepatitis A virus and the gastroenteritis viruses.

Explosive outbreaks caused by the contamination of drinking water by these viruses have been documented. Recently, CDC reported a gastroenteritis outbreak (presumed to be viral) affecting about 200 swimmers. Tests on the water before and after the outbreak did not show elevated indicator bacteria counts at the swimming site. Obviously, this agent is very virulent and produces disease in all age groups. I think it is appropriate for environmental virologists to now focus on these agents and possibly put less of our energy and resources into studies of the enteroviruses.

MR. PAHREN: A question just occurred to me and perhaps I will direct it to Dr. Clark. In thinking about John Phair's paper, do you think that the heroic efforts of phagocytes and polymorphonuclear leukocytes might be one of the reasons that we are not seeing effects in exposed personnel? I am referring to the fact that in many of these exposure cases you do not see increases in antibody. Is this the case because of the cell-mediated immunity whereby foreign matter is phagocytized before it initiates the antibody response?

DR. CLARK: White blood cell (leukocyte) counts were routinely performed during the annual health examinations given study participants. Elevations among sewage exposed workers were not detected, however. It is possible that testing performed more frequently would have detected elevations. In our health study of sewage treatment plant sludge composting workers complete blood counts are being performed several times per year.

DR. SINGAL: I think many of the bacteria we are talking about in normal intestinal flora are common environmental bacteria that don't cause infection *per se*. *Salmonella* and *Shigella* are relatively uncommon in infectious amounts. Whatever *Salmonella* and *Shigella* find their way into the sewers are greatly diluted by the time they reach the sewage treatment plant. I don't recall any of the papers that tried to measure them and actually found them. Is that everybody else's recollection too?

DR. CLARK: We found a few *Salmonella*.

DR. SINGAL: In the sewage?

DR. CLARK: No, in rectal swabs.

DR. SINGAL: Okay, so in the case of bacteria, I think the primary reason you didn't see infections was there was probably seldom exposure to an infectious dose of the pathogen. In the case of the viruses, probably the first exposure causes, in most adults, a non-illness infection, a sub-clinical infection if you will. Then subsequent to that there is humoral antibody protection.

DR. JOHNSON: I think that we probably are underestimating public interest in environmental issues on health effects at sewage plants.

MR. WITHERELL: Coming from a rural area I am concerned about the aerosols that are generated with more conventional types of treatment for rural areas, mechanical aeration, and we are going into oxidation ponds to a great extent. We are also getting some spray irrigation. To date we are recommending spray irrigation only after secondary treatment, but I think the push is on from an economic standpoint to do as little pre-treatment as possible, i.e., taking raw sewage, grinding it up and spraying it on the fields to keep costs down. But what are the health effects of those aerosols? It seems to me that we should encourage responsible investigation into this.

DR. SINGAL: Community outbreaks may be an appropriate time to look at the community around the treatment plant and at the workers at the plant. We should see what the attack rate was among them compared to the rest of the community and where they fit on the disease curve. I think if it turns out that they were rather late in the curve, that might suggest that their source of exposure was everybody else's excretion.

DR. CLIVER: I have a lot running through my head in the last few minutes. On the one hand we heard early on that there was a great difficulty in getting representative samples of aerosols and, on the other hand, the model that I tried to construct of what hazards there might be in regard to aerosol had a great deal to do with the problem of sampling the sewage plants and determining what is being contaminated by the aerosols directly. I couldn't help but think that, for some of these infections, we already have other ways to extract the data. Maybe what we need to do is place ham sandwiches in key places around one of these aerosol generating plants to see if we can detect which areas this infection is spreading from.

MR. McCABE: I think certainly what Dean says has been an issue with the FDA and the chickens, by introducing every house to a big batch of *Salmonella* every time you buy a chicken. That is a problem. Granted the chicken is cooked, but if you innoculate everything else on the kitchen sink, I think there is some merit to that idea. There might be something that you could do among the neighbors.

DR. SINGAL: Are you suggesting that a 50-cent ham sandwich is a better measuring device than those $3,000 instruments?

MR. McCABE: Probably.

MR. SCHWARTZ: In talking with a number of plant operators around this area, I find that some plants are issuing up to 7 to even 10 changes of protective clothing per week. This is a work uniform. Is there any new push in either NIOSH or EPA to develop a set of health standards?

DR. SINGAL: I am not aware of any NIOSH work specifically on work standards for sewage treatment workers.

MR. McCABE: I don't know how EPA is going to have that happen. We are certainly not going to do it. NIOSH is not doing it. It looks like it is in the crack.

MR. PAHREN: Well, Dr. Clark mentioned that 8 years ago he approached NIOSH about their interest in looking at the occupational health of workers, and they said that if he found a hazard to let them know and they will proceed. Now, is there sufficient evidence for NIOSH to proceed or not? Or will they have to consider the material in the proceedings?

MR. SCHWARTZ: One of the reasons I bring this up is because I have seen some of the contents from operator short courses, under the direction of the State of Ohio, which suggest to employees that they not only shower before they go home but that they not take their work clothes home. If they do, they should be sure not to wash it with those of their family because of the potential of infectious organisms that might have adhered to their clothing.

DR. SINGAL: In my personal opinion, it seems like a good idea, even though we haven't documented any transmission. Based on the precedent for working with other hazardous materials, it would be certainly consistent with NIOSH recommendations and OSHA regulations concerning other hazardous materials, either chemicals or biologic agents.

MR. PAHREN: In the meantime I think common sense should prevail.

DR. LUE-HING: For the general worker in the plant I don't think we have any special program for the clothes. For workers who have to enter sewers, at least in the R&D department, we manage the industrial waste control program, and in some instances we have disposable clothes. If we are investigating an explosion in a pesticide plant, we would go in with disposable clothes. You walk out, take it off, shower and get out. But we don't have any program of that type for the in-plant, 8:00 to 5:00 worker.

MR. SCHWARTZ: If I might make one more comment on this, one of the things that is increasing in practice is the storing of wastewater samples in the same refrigerator with employee lunches. I think that that should not be tolerated.

MR. PAHREN: This applies not only to sewage treatment plants but to research laboratories.

DR. LUE-HING: We don't permit that in Chicago. I do have a couple of comments on disinfection if I might make them. The gentleman was concerned about spray irrigation. I cannot speak to that question specificially, but in the State of Illinois, we have petitioned the state to abandon its requirements for chlorination of secondary effluents for several reasons: 1) we cannot document where it presents a hazard to the citizens of the state; 2) it costs too much; and 3) if one looks at the data with and without chlorination, they are indistinguishable. For example, the requirements of the state say you should chlorinate to 400 fecal coliform organisms/100 ml. In a 60-day continuous, 24-hour a day, sampling study at a plant, we found that the unchlorinated effluent for those 60 days had a mean of less than 1,000/100 ml. When you are talking about sewage, those two numbers, to me, are back to back. For these and other reasons, we are petitioning that the requirement be abandoned.

MR. PAHREN: Let us now close the symposium. Thank you all for attending. I hope it has been worthwhile and that the information presented will serve the scientific community and regulatory agencies.

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